# DEVELOPMENT OF AN AUTOMATED ULTRASONIC C-SCAN SYSTEM FOR COMPOSITE MATERIALS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

*by*

SHEKHAR Y. MAHAJAN

*to the*

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

**SEPTEMBER, 1989**

ME-1989-M-MAH-DEV

TO MY FAMILY MEMBERS

15/9/8

## CERTIFICATE

This is to certify that the thesis entitled "Development o an automated ultrasonic C-Scan system for composite materials" b Shekhar Y. Mahajan is a record of the work carried out under ou supervision, and has not been submitted elsewhere for a degree.

N N Kishore 14/9

Dr. N. N. KISHORE

Assistant Professor
Dept. of Mech. Engg.
I. I. T. Kanpur

B D Agarwal 14/9/89

Dr. B. D. AGARWAL

Professor
Dept. of Mech. Engg.
I. I. T. Kanpur

## ACKNOWLEDGEMENTS

I wish to express my deep sense of gratitude and appreaciation to my advisors Prof. B.D. Agarwal and Dr. N. N. Kishore for their valuable guidance throghout the present work. Their generus attitude towards the academic liberty has been a constant source of inspiration for me.

I am indebited to Dr. K. Ramesh for his technical and moral support during the tenure of my work.

I am grateful to Prof.R.N.Biswas for his valuable suggestions.

I am thankful to my friends Mr. Murali and Mr.Nitin Gogate for their invaluable help in the present work. I deeply appreciate the discussions and helpful comments of Dr.B. Rai, Mr.K.K.Bajpai,Mr.Raghuram and Mr. Khadilkar..

I highly value the association with Mr. V.R.Ganeshan, Mr. Wandhekar and Mr. Singhi with whom I shared many ideas and all those who supported me during my tenure.

I wish to thank Mr. shukla and Mr. D. K. Sarkar for the excellent photographs.

Thanks are due to Mr. S.L. Srivastva, Mr. Singh, Mr. Arun and Mr. Sudhir for their timely help.

## CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

## LIST OF SYMBOLS

| | |
|---|---|
| E | MODULUS OF ELASTICITY |
| G | SHEAR MODULUS |
| $\mu$ | POISSON RATIO |
| $\sigma$ | DENSITY OF MATERIAL |
| Z | ACOUSTIC IMPEDANCE |
| V | VELOCITY OF OSCILLATION OF PARTICLES |
| P | ACOUSTIC PRESSURE |
| R | COEFFICIENT OF REFLECTION |
| D | COEFFICIENT OF TRANSMISSION |
| $\lambda$ | WAVELENGTH OF WAVES |
| T | TRANSMITTER |
| R | RECEIVER |
| Ç | VELOCITY |

**ABSTRACT**

Materials have become a key factor of technical evolution in the modern era. Composite materials are among the promising engineering materials with a variety of application fields. The light weight high strength composites are ideally suited for aerospace structural applications. High levels of reliability must be ensured in such structures and therefore non destructive testing plays a major role in their quality assurance. Ultrasonic inspection has proved to be an effective means to evaluate the non homogeneous and anisotropic composite materials. The availability of computers has had strong influence the ultrasonic NDT instrumentation towards automation.

In the present work, a microcomputer based ultrasonic inspection system is developed by interfacing the available scanning set up with a PC-XT. The present system uses the peak amplitude analysis of the received ultrasonic signal for C-scan imaging of the composite specimens. The fall in the value of the peak amplitude of the received signal indicates the presence of a flaw in an otherwise undamaged specimen. A peak detector circuit is developed for detecting the peak amplitude of the received signal and an analog to digital converter (ADC) is used for transferring the data t PC. Image processing techniques are used for presenting the acquired information. The two dimensional flaw image is displayed on the colour monitor with pseudo colouring scheme aiding in detection and sizing of defects in the composites.

The composite laminates with artificially introduced flaws were tested using the present set up. Kevlar fiber and glass fiber specimens subjected to impact test were also examined for the damage. The C-scan image shows more damage areas than those that can be identified by visual inspection.

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

In the modern age, there has been an increasing demand for materials ever stiffer and lighter in weight by various application fields. The demands are so extreme and diverse that no one material is able to satisfy them. This naturally led to a resurgence of the ancient concept of combining different materials in an integral - composite manner, to satisfy the user requirements. In effect, the composites have introduced an extraordinary fluidity to design engineering offering flexibility to the designer to create tailor made composites for each application. Due to outstanding strength, stiffness, fatigue resistance coupled with light weight their use is expanding rapidly in the diverse fields like space, aeronautics, energy, civil construction etc. New highly stressed components are regularly announced with advent of advanced fibres like boron, carbon, silicon carbide for reinforcing resin, metal and ceramic matrices.

The use of Non Destructive Testing ( NDT ) for structural integrity of such components is very essential if these materials are to continue to be considered as the first choice for highly stressed components. The task of NDT in composites differs from that in metals where there is more complete understanding of the related failure micromechanisms . Composites present novel problems for non destructive testing. Generally

these materials have poor electrical conductivity, low thermal conductivity, high acoustic attenuation. It is a heterogeneous medium which can contain multiple defect geometries. No single model can adequately describe the level of damage which is critical.

Measurement of ultrasonic attenuation is most widely used technique for determining the quality of the composites. Several material parameters influence the ultrasound propagation in composite materials. First and foremost are the stiffness properties and densities of the material which determine the direction and energy partitioning of the ultrasonic beam within the material. Secondly, the microstructures features like fibre volume fraction, porosity, delaminations, ply orientations influence the ultrasonic sound propagation characteristics.

Advancement in digital technology has had large impact on developments in ultrasonic instrumentation and wide range of processors have been incorporated in a variety of systems and instruments. Computers play an important role in the design of inspections, in the acquisition of data, and in the processing, evaluation and ultimately,presentation of the data. The ability to acquire and record large digital data by computers gives a significant increase in reliability of inspection by elimination of the human operator's potential for missing significant echoes and by automated production there is an evidence that the required material has been scanned. Sophisticated data processing procedures to enhance signal to noise can also be introduced if the application demands it. The introduction of computer based

aids to data evaluation also becomes possible. Reliability is further enhanced and repeatability increases if the probes scan the specimen automatically.

## 1.2 LITERATURE SURVEY

There are large number of non destructive testing techniques varying in applications and operating principles. The current state of the art of widely accepted NDT techniques is summarized below.

**Acoustic emission** : This technique deals with the analysis of stress waves formed due to the release in strain energy during the material deformation. Comprehensive review of this technique is provided by Arrington [1]. Computers are now widely used in signal analysis for event counting, ringdown counting, amplitude analysis, energy analysis and event duration [2].

**Radiography**: To produce an X-ray or gamma ray radiograph, a beam of the radiation is directed towards the object that is to be investigated. The differences in intensities is caused by differences in density and thickness of the object. Use of radiographic technique for composites is described in [3]. Computer assisted radiography consists of image acquisition and image conditioning system. Such system developed for composites is described in [4].

**Thermal NDT**: Thermal imaging of composites is possible by recording thermal field generated by stress. The hot spots generated in the regions of damage under cyclic loading are evident in the specimen of low thermal conductivity such as glass

fibre reinforced composites [5].

**Optical techniques:** These include laser scanning, Moire fringe fringe method, holographic interferometry, Speckle methods etc. Detailed review of these methods with the current trends is given in [6].

**Ultrasonic Techniques:** Ultrasonic signal analysis is the most popular technique for inspection of the composites.

In 1942, Firestone was first to apply the principle of sonic depth finder, well known for ship locating and depth sounding at sea [7]. After 1945, favored by the increasingly urgent demands for non destructive testing, this method became generally accepted as a practical tool.

The conventional Ultrasonic inspection system operates in a manner analogous to that of sonar echo location. A short burst of high frequency sound is emitted from a transducer which is coupled to the object being inspected. The Ultrasonic pulse travels through the test specimen and gets reflected from or refracted at discontinuities and interfaces. The reflected or transmitted signal is picked up for detecting the presence of the defects which reveal themselves by drop in sound intensity as compared with defect free locations [8] .

Ultrasonics is a branch of NDT that has received most attention as regards to interpretation and manipulation of the received signal. This is partly because of very wide applicability of the technique but also because of the complexity of interactions between the ultrasonic pulses and defects.

The Ultrasonic C-scan inspection procedure is one of the well accepted inspection procedures for testing of the composite materials. An image obtained by amplitude analysis at a particular depth can show most of the potentially defective areas inside a structure. C-scan testing can be carried out in a pulse echo mode,through transmission mode and other variations to examine multiple reflections, etc. [9]. The Ultrasonic C-scan technique is capable of measuring delaminations, ply gaps and inclusions in composites [10,11]. It can also detect resin rich, resin starved areas, surface scratches etc.[12,13]. Incorrect cure of matrix is likely to result in increased material damping and increased attenuation [14,15]. Rose and Carson [16] demonstrated use of C-scanning for the early detection of fatigue damage and the prediction of the remaining life. The resolution of Ultrasonic C-scan technique is limited by dispersion in composites and by beam dimensions. As a consequence, C-scanning is more reliable as an indicator of overall quality than as determination of specific defects [17].

Ultrasonic velocity measurements have been made by a number of researchers and it has the advantage of of being simple to measure accurately in all but very thin specimens. Reynolds and Wilkinson [18] have shown that the velocity of ultrasonic waves traveling normal to the fibre plane is a function of the porosity and fibre volume fraction. Kaelble and Dynes [19] have shown that ultrasonic velocity measurements may be used to monitor moisture ingress to composite.

Ultrasonic back scattering technique involves the use of transducer at an acute angle to the test surface followed by rotating it about an axis normal to the test surface and the echoes are monitored. A plot of the signal intensity versus the angle of rotation can be used to detect local fibre waviness, translaminar cracks and ply end discontinuities [20,21].

In Ultrasonic spectroscopy technique, the frequency content of a pulse that has traveled through a test specimen is analysed by spectrum analysis. Cousins and Markham [22] succeeded in using this technique to determine the depth of delaminations in perspex and carbon fibre composites with artificial delaminations. High speed digital transient systems are coupled to Fast Fourier Transform processors to give improved frequency resolution [23]. If a composite is to be inspected for a variety of defects, then it may be beneficial to process ultrasonic test signal in both, time domain and frequency domain. Using this approach, Rose and coworkers have developed a feature mapping system for the classification of defects in composites [24,25]. Another of the better established NDE techniques based on ultrasonics is Fokker-Bond tester [26] where frequency and amplitude changes are monitored. Changes in resonant frequency reveal the existence and depth of delaminations.

Generally, the measurement of an attenuated signal is done by feeding it to cathode ray tube . This trace on the CRT screen is further used for defect detection. Visual inspection of the screen traces is often too slow and error prone . Processing of

the test data in the form of electrical values is therefore, desirable and essential for most documentation methods. Necessary requirements for data acquisition are described by Engl and Smithz [27]. It is possible to employ go-no go monitor which may activate recorder or signaling device like a horn or bell to indicate the presence of the defect [8].

NDE of composites requires gathering of large amount of data, statistically processing it, using numerical techniques, and comparing it with a reference data bank. This work, which is time consuming and may involve human error, requires computerisation. Use of computerised systems has contributed significantly to the ability to acquire a large quantity of data and process, display, and store it in automatic and reliable fashion [28]. In recent years, computerised C-scan systems are widely used for research and development. Ultrasonic parameters sensitive to various defects have been evaluated with the aid of proper computer software to provide detailed information about defects [29].

## 1.3 SCOPE OF THE WORK

The availability of computing power in small packages at lower costs has had strong influence on the design of instrumentation used for acquiring and processing data generated during Ultrasonic testing.

In our laboratory, a mechanized scanning system interfaced with UFD is available for testing of composite laminates [30]. It can be used to scan the specimen automaticaly and produce C-scan

output using the flaw alarm circuit in the UFD. In the present work it is proposed to extend its capabilities with the use of a microcomputer ( PC-XT ). A circuit is designed to detect the peak amplitude of the received signal. Then the amplitude value is digitized and stored in the PC along with the geometric location of the probe.

Chapter 2 outlines the fundamentals of the ultrasonic technique to find the flaws in material.

Chapter 3 describes the details of available set up for C-scanning and the design and the development of the present set up. Also presented are the details regarding the analysis of the data and presentation using image processing card.

Results and discussions are presented in chapter 4 and conclusion is summerised in chapter 5.

# CHAPTER 2

# ULTRASONIC INSPECTION TECHNIQUES

## 2.1 INTRODUCTION

Human ear can sense frequencies in the range of 20 Hz to 20KHz. The frequency higher than this range is above-sonic or 'ultra'-sonic.

These ultrasound waves can be used for various applications. One class uses high energy ultrasound while other class makes use of low energy waves.

**High energy applications:**

1)Welding of metals

2)Impact grinding

3)Deburring

4)Electroplating

5)Relief of residual stresses.

**Low energy applications:**

1)Flaw detection

2)Density measurement

3)Viscosity measurement

4)Thickness measurement

5)Food inspection

Ultrasound for the flaw detection was first suggested by Sokolov. For commercial use Ultrasonic NDT is widely accepted technique as it enjoys certain advantages over other non

destructive techniques. Ultrasound waves have **high penetration power**. It is possible to check up to 10 meters of steel by proper choice of frequency. Also **instantaneous information** can be obtained regarding the presence of the flaw just by visual inspection of received signal trace on the oscilloscope screen. The **Portable instruments** allow the inspection of large containers, boilers, penstocks during service . Defect characterisation is possible by the detailed analysis of the received signal. The proper choice of the transducers and frequency range makes **detection of small flaws** possible. The method is **versatile** and wide range of materials can be tested.

## 2.2 Properties of Ultrasonic waves

Acoustic waves behave just like light waves. Therefore, all the properties of the light waves are also applicable for acoustic waves.

### 2.2.1 Modes of propagation

The propagation of acoustic waves through a medium is determined by the oscillation modes of particles constituting the medium. For longitudinal wave the direction of propagation of sound and direction of oscillations are parallel and the wave is propagated with alternate compression and dilation of the medium. In the transverse wave periodic shear force is responsible for sinusoidal up and down motion of the particles and the direction of propagation and direction of oscillation are at right angles to each other. Since liquids and gases are practically incapable of transmitting the shear force, transverse waves can attain

appreciable distance only in solids. Rayleigh wave or shear wave exists on a flat boundary of a solid substance where oscillatory motion of the particle is elliptic. Lamb waves which have got considerable importance for testing of materials are the plate waves which can contain components of particle oscillation at right angles to the surface.

### 2.2.2 Acousto optics

Acoustic waves can exhibit the phenomenas similar to optical effects like reflection, refraction, diffraction, interference due to the wave nature of sound. It is also possible to construct a sonic wavefront using Hygiene's principle.

The velocities of the various kinds of sound waves can be calculated from the elastic constants of the material concerned. The velocity of longitudinal wave in a medium is given by,

$$C = \sqrt{\frac{E\ (1-\mu)}{\sigma\ (1+\mu)\ (1-2\mu)}}$$

For transverse waves the velocity is given by,

$$C = \sqrt{\frac{E}{\sigma}\ \frac{1}{2(1+\mu)}} = \sqrt{\frac{G}{\sigma}}$$

Where, C - Velocity in m/sec.

E - Modulus of elasticity in $N/mm^2$

$\mu$ - poisson ratio

$\sigma$ - Density of material in $Kg/m^3$

G - Shear modulus in $N/mm^2$.

These velocities can be used to calculate acoustic impedance of the material.

### 2.2.3 Impedance and Impedance Matching

The electrical impedance is defined as ratio of electrical potential to current. In acoustics, pressure P and velocity of oscillation of particles correspond to electrical potential and current respectively and acoustic impedance Z is defined as,

$$Z = P/V$$

it can be shown further that,

$$Z = \sigma . C$$

Where

$\sigma$ - Density of the transmitting medium,

C - Velocity of sound through the medium.

Importance of Impedance matching for inspection techniques is described below.

When a plane acoustic wave is passing through material 1, with acoustic impedance $Z_1$, to a material 2, with acoustic impedance $Z_2$, part of energy is transmitted to material 2 and remaining is reflected back into material 1 . Assuming the sound wave strikes at right angles to the plane of interface, the coefficient of reflection (R) and the coefficient of transmission (D) are given by,

$$R = \frac{Pr}{Pe} = \frac{Z_2 - Z_1}{Z_1 + Z_2}$$

$$D = \frac{Pt}{Pe} = \frac{2\ Z_2}{Z_1 + Z_2}$$

Where

Pe - Incident sound pressure,

Pr - Reflected sound pressure,

Pt - Transmitted sound pressure.

For perspex air interface,

$Z_{air} = \sigma_{air} \cdot C_{air} = 1.3 Kg/m^3 * 330\ m/s = 429\ Kg/m^2 sec.$

$Z_{perspex} = \sigma_{per} \cdot C_{per} = 1.18 * 10^3 Kg/m^3 * 3.2 * 10^3 m/s$

$= 3.221 * 10^6\ Kg/m^2 s$

Thus, coefficient of reflection R is nearly equal to unity and coefficient of transmission is equal to 0.00026. Therefore, almost all the energy is reflected back to perspex and negligibly small part is transmitted. Hence suitable medium or a couplant is necessary in between the transducer and the test specimen. In the present case, water is used as couplant between the transducers and the composite specimen .

### 2.2.4 Sound field

For satisfactory results, the distance between the transducer and the test specimen should be larger than certain minimum value. For determination of the optimum distance, analysis of sound field in front of the transducer is necessary.

The sound field, just in front of the oscillator gets modified by the diffraction phenomena and maximas and minimas are formed due to interference. The length of this interference field is determined by the diameter of the oscillator, D and the wavelength, $\lambda$.

The distance of the interference field from the oscillator diaphragm measured along the axis of the transducer is given by,

$$N = \frac{D^2 - \lambda^2}{4.\lambda}$$

The sound field up to the distance N is also termed as near field and the sound field after this range as far field. The near field zone is complex and none of the acoustic pressure curves of cross section in this zone are smooth. This range can not be used for the flaw detection purpose. Far field zone is simpler and consists of nearly smooth acoustic pressure curves of cross section. This zone is always used for inspection and thus the distance of the transducer from the specimen should always be larger than the length of the near field.

### 2.2.4 Effect of obstacle in sound path

A flaw in the test object represents an obstacle in sound path. The information regarding the flaws can be obtained either via reflected wave i.e. the echo or the transmitted wave i.e. the shadow. If the dimension of a flaw is larger than the wavelength of ultrasonic signal, the incident wave is reflected completes which results in total shadow zone behind the flaw. If the defects are small, comparable with the wavelength, then

diffraction phenomena decides the echo and the shadow.

**Echo effect:** This can be analysed by considering the small circular disk placed in far field zone of the sound path as an obstacle. Then the circular disk will be illuminated almost uniformly. All the points of the disc become the origins of elementary waves, all equal in phase and amplitude and the area of the disc becomes secondary oscillator with its own near field zone. If the distance between the transmitter and reflector is much greater than both the near fields together, then sound pressure of the reflected wave can be calculated from the simple mathematical relations.

**Shadow effect:** An obstruction in sound field disturbs the propagation of waves not only due to the reflection of waves but also due to the shadow effect. If the dimension of obstruction exceeds very much as compared with wavelength of sound,there will be lack of sound field behind the obstruction i.e. shadow. For smaller flaws, this shadow field is modified by diffraction. Using theoretical physics, it can be shown that the interference field behind the circular disc is complementary to the field created by the reflected wave (secondary oscillator field).

## 2.3 Methods For Ultrasonic Testing

Two widely accepted methods for the composite laminates testing are described below :

### 2.3.1 Through Transmission Method

This method is preferred primarily because of the simplicity

and reliability it offers in the flaw detection.

It uses two different probes for sound emission and reception as shown in Fig. 2.1 (a). Two surfaces of the specimen should be accessible with the two probes positioned exactly above each other over these surfaces . Ultrasonic energy is sent by an emitting transducer into one surface . The ultrasonic waves after traversing through the specimen thickness, emerge out at the opposite face . These waves are collected by the receiving transducer and evaluated for the presence of flaws. This detection capability is due to the impedance mismatch, pulse reflections, attenuation and dispersion, thereby reducing the peak amplitude of the received signal. The received signals for specimen with flaw and without flaw are shown in the figure . The method is capable of measuring delaminations, ply gaps, inclusions, fiber breakage and voids.

### 2.3.2 Pulse - Echo Method

In this method, the emitting transducer as well as the receiving transducer are mounted over same side of the specimen as shown in Fig 2.1(b). The ultrasound waves are sent into the specimen by an emitting transducer which are reflected by the back surface of the specimen. The reflected waves are collected by the receiving transducer and further analysed. If flaws are not encountered, sound has to travel through double the thickness of the specimen before reaching the receiving transducer. If the flaw is present, sound waves are reflected back from the surface of the flaw. This reflected signal is attenuated due to the

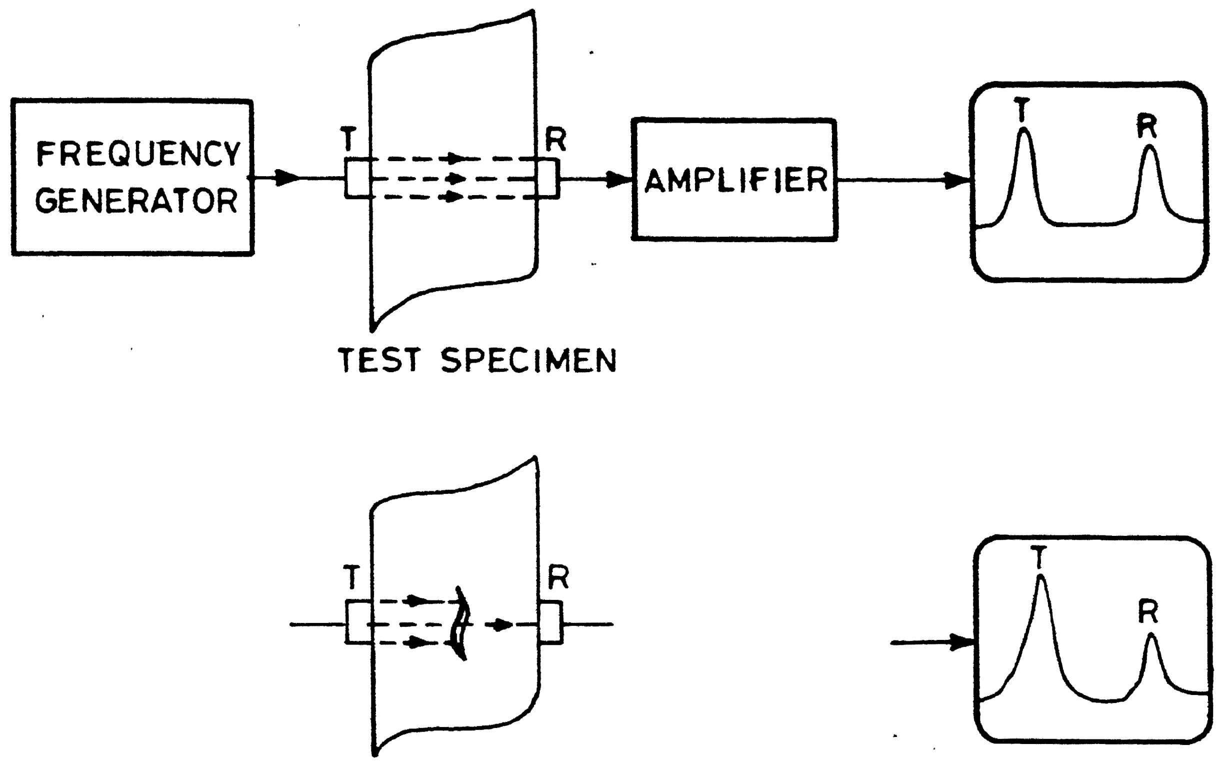



Fig.2.1(a) Through transmission method.

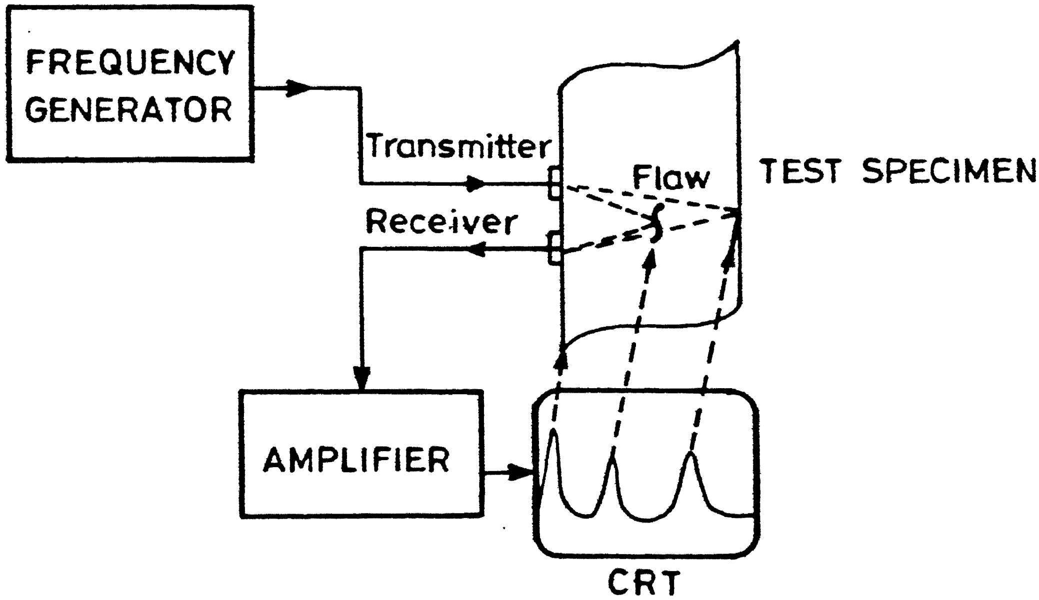



Fig.2.1(b) Pulse echo method.

absorption and impedance mismatch. The traces of the emitted and received signal when a flaw is present are shown in the figure.

This method can be conveniently used where other side of the specimen is not accessible. It can measure depth of the flaw and thickness of the specimen .

## 2.4 Techniques of Ultrasonic Testing

Two basic testing techniques using either through transmission or the pulse echo method are : (a) Contact testing (b) Immersion testing.

(i) **Contact testing**: In this technique the probes are brought in contact with the test specimen through a thin layer of a couplant and the energy transmitted from the flaw is picked up by the receiving probe. This technique is frequently used for large specimens.

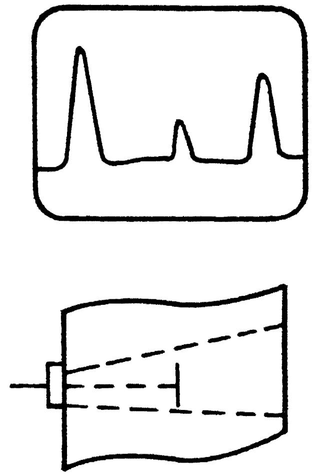
(ii) **Immersion testing**: In this technique the probe are immersed in a liquid (water or oil). The liquid acts as a couplant between the specimen and transducers. As the presence of couplant is always ensured, the technique is generally used for high quality testing. It is suitable for small specimens that can be immersed in the tank. .

## 2.5 Flaw Representation Techniques

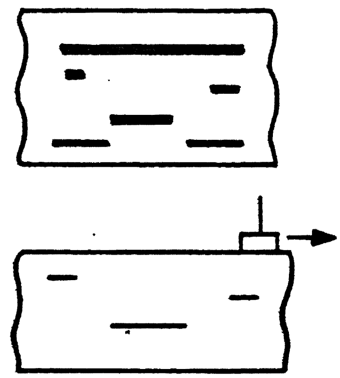
Ultrasonic testing basically involves real-time measurement of ultrasonic energy. As it is difficult to comprehend and directly analyse this form of energy, it is converted into more

suitable visual representations.

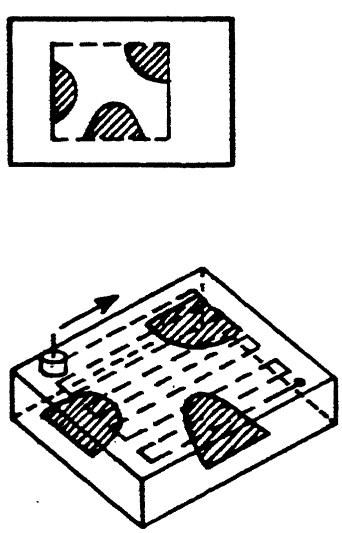
Usually ultrasonic energy is converted into electrical signal and is represented on the screen of cathode ray tube. The vertical axis of the screen depicts the amplitude of the transmitted and received signals in correct sequence, while the horizontal axis indicates the elapsed time between both. By analysing the signal display pattern on the screen, information for the flaw can be obtained. The representation of signal trace on the oscilloscope indicating presence the flaw at a given test point is termed as A-Scan. In order to cover the given cross-section, it is necessary to shift the probe along a test line as shown in Fig. 2.2 . This one dimensional representation of the specimen for flaw along the line is commonly called the B-Scan representation. In case of two dimensional scanning (area) of a test piece, e.g. a composite plate, the test results are obtained by scanning transducers over area and are represented by C-Scan. This furnishes top view of the test piece with plotted flaw projection points. Figure 2.2 gives clear idea about the presentation methods.



A - Scan



B - Scan



C - Scan

Fig. 2.2 A-Scan, B-Scan, C-Scan representations.

# CHAPTER 3

# DESIGN AND IMPLEMENTATION OF C-SCANNER

This chapter describes the development of the system for generating Ultrasonic C-Scan images using PC-XT. The following sections give the brief description of the available scanner with its capabilities and the present work of interfacing it with an IBM-PC compatible to obtain C-scans using the image processing techniques.

## 3.1 Available Set-Up

A basic mechanical scanner interfaced with the ultrasonic flaw detector (UFD) was developed by Shukla [30] in Composite Materials laboratory of IIT, Kanpur . It uses through transmission technique with water immersion method for the C-Scan representation of the specimen. The block diagram of the system is shown in Fig. 3.1 .

The test specimen is mounted in an immersion tank, filled with water. Two transducers are coaxially mounted on a bracket so that they are on either side of the test specimen. The transducer set moves along a path shown in the figure , with the help of two stepper motors. These motors in turn, are controlled by a digital control circuit. The counters are used to set the portion of the specimen to be scanned automatically. The ultrasonic flaw detector (UFD) generates the signal to energize the emitting transducer. The ultrasonic signal passes through

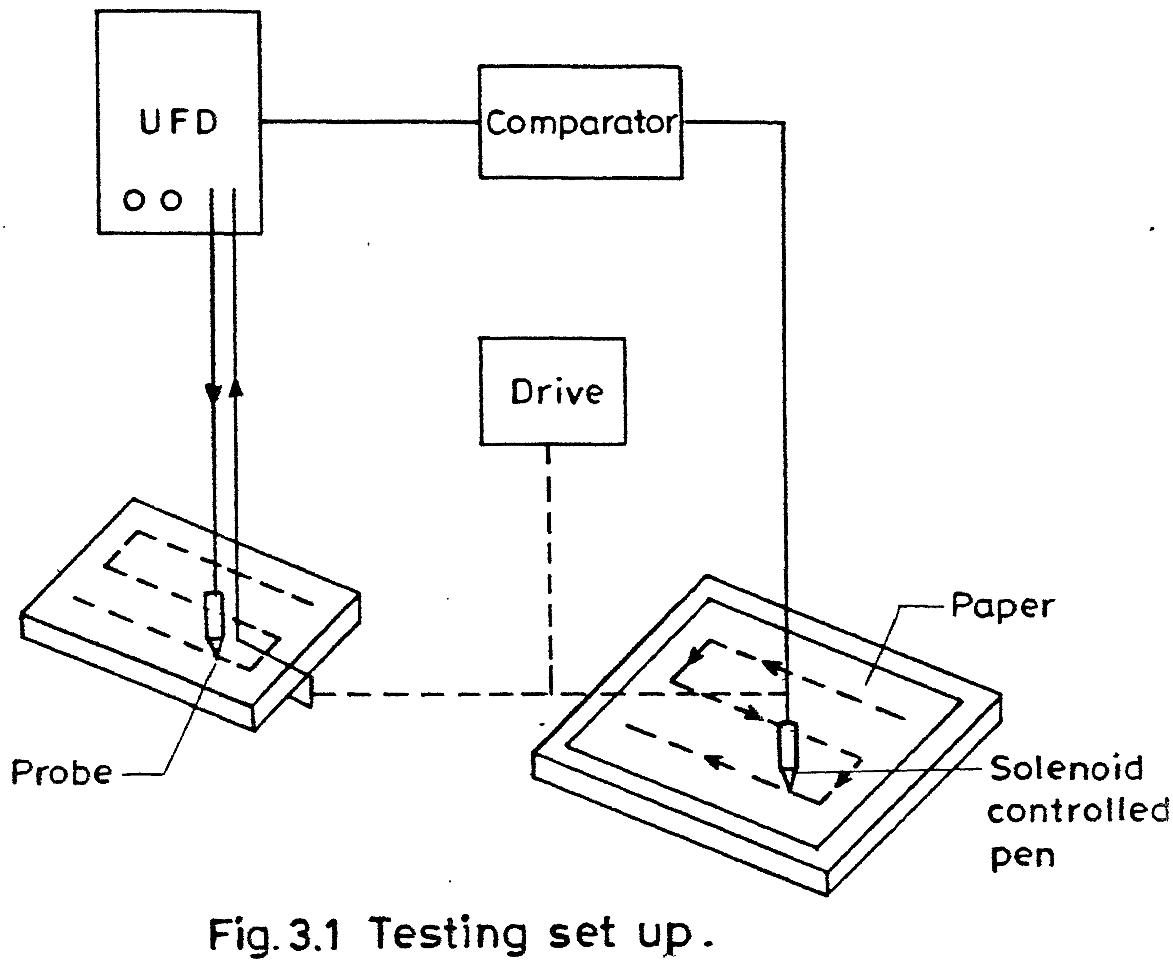



Fig. 3.1 Testing set up.

the specimen and is collected by the receiving transducer which is then fed back to the UFD. The trace of the emitted signal and received signal can be seen on the screen of the ultrasonic flaw detector . Analysis of the received signal gives an idea about the flaw in the specimen. The UFD has a built in comparator which compares the received signal amplitude with a threshold and sends GO-NOGO signal to Flaw Alarm Monitor. This signal is used to lift or press a pen which also moves synchronously with the probes. Thus, it is possible to plot the flaw projection when a flaw is encountered.

### 3.1.1 Ultrasonic Flaw Detector

Ultrasonic flaw detector UFD 6255, manufactured by ECIL, India has been used for the present work. This equipment displays A scan representations on a CRT screen . The salient features of the equipment are noted below :

I) It provides ultrasonic pulses in the frequency range of 1.5 to 10 MHz. It is compatible with a variety of probes and has the capabilities of measuring flaws in steel specimens of thickness in range of 0.7 cm. to 10 meters .

II) The rate at which ultrasonic pulses are sent can be varied to suit the depth range of the test component.

III) Gain of the received signal amplifier can be controlled externally (maximum gain = 120 db). The unwanted noise signals can be rejected to reduce the flare on the screen.

IV) The equipment has Flaw Alarm Monitor (FAM) facility which gives an alarm when the received signal amplitude falls below the set threshold value.

V) The displayed echoes can be widened 3 to 4 times the original.

VI) Other important specifications are as follows :

1) Dead Zone : Ø.7 cm for 2.5 MHz frequency probe.
2) Delay : Ø to 4 meters of steel in two steps
3) Calibrated Attenuator : Ø to 62 db.
4) Accuracy : 15 %

The detailed information regarding the operation and various circuit diagrams are given in ECIL manual (29).

### 3.1.2 Stepper Motor Control Circuit

The transducers scan the rectangular areas along the path A-B-C-D-E-F as shown in Fig. 3.2 . The movements along two perpendicular directions are provided by two separate stepper motors. It can be seen that the transducers are moved along the straight lines AB, CD, and EF by one stepper motor and along BC and DE by the other motor. Further, the direction of rotation of the stepper motor during the transducer movement from C to D is opposite to that during A to B. The second motor rotates in the same direction as the traansducers move from B to C and D to E. Thus, the complete scanning can be achieved by four motions of the stepper motors for transducers to traverse path ABCDE and repeating them sufficient number of times. The block diagram of the stepper motor controlling circuit is shown in Fig. 3.3. A sequence generator circuit is used to produce the four motions

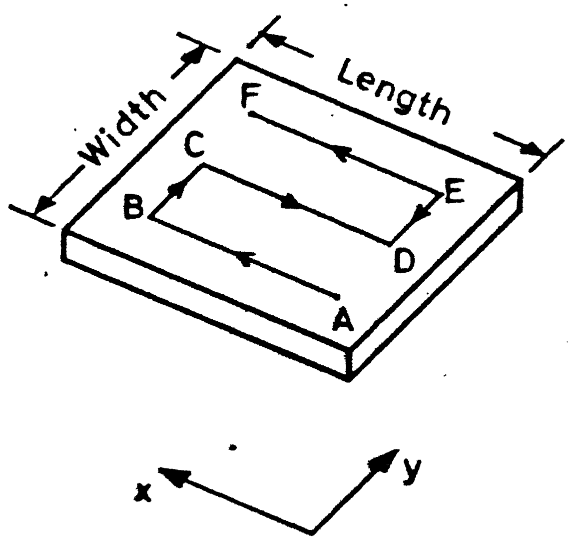



Fig. 3.2 Probe's scan pattern over the specimen.

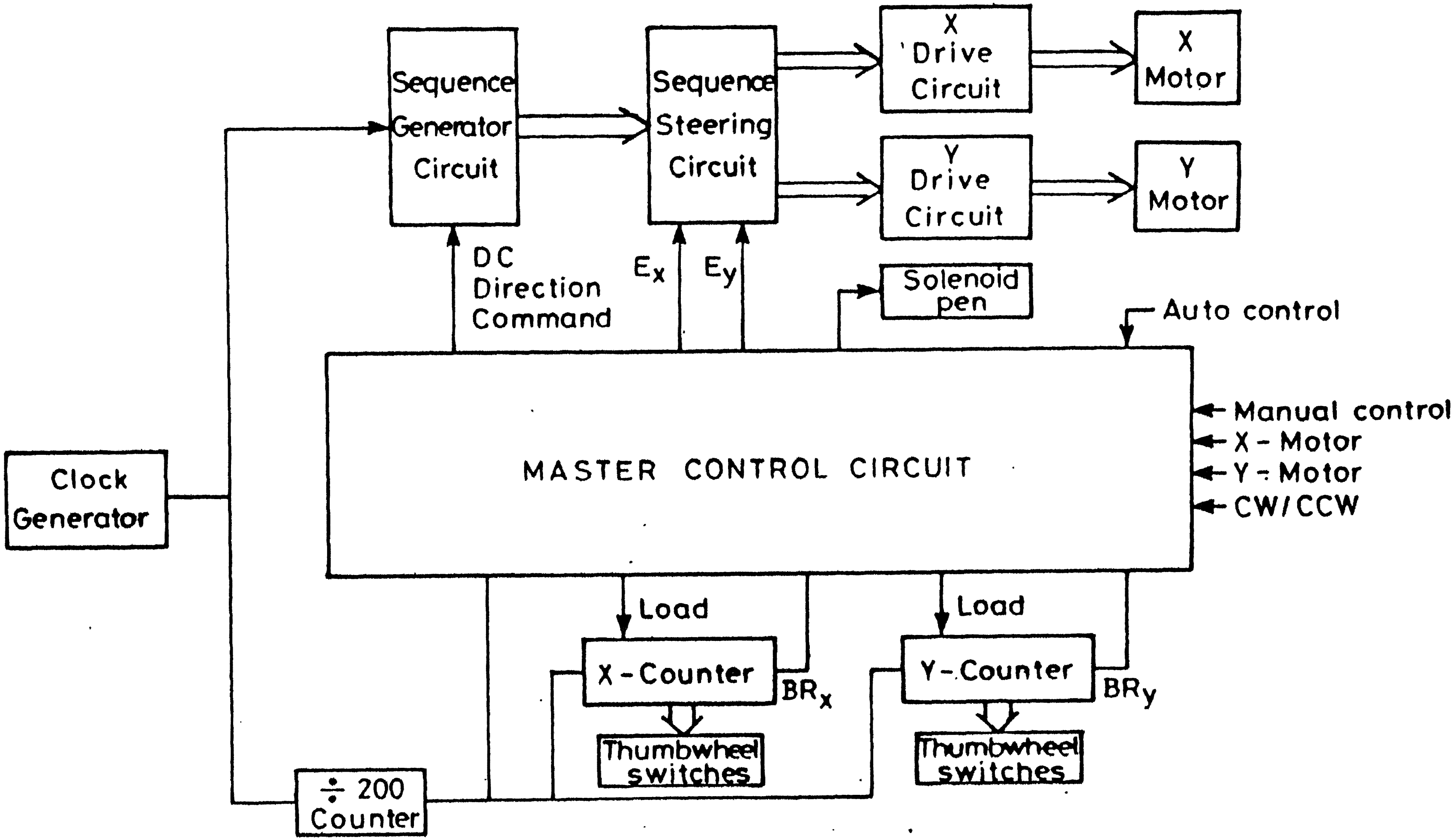



Fig. 3.3 Block diagram of the digital control system of the scanner

and repeating them. The sequence generator circuit receives pulses from a clock generator and sends them to a appropriate stepper motor driving circuit in the predetermined sequence. Duration of each of the four motions depends upon the lengths of the paths AB, BC, CD and DE. The paths AB and CD have the same lengths as the length of the area to be scanned while the paths BC and DE are designed to be of 1 mm length. Durations of each of the four motions is controlled by a master control circuit with the help of two counters which keep count of pulses sent by the clock generator to the sequence generator circuit. With the present design, 200 clock pulses of the clock generator rotate the stepper motors by one revolution and the transducers by 1 mm. The length of the area to be scanned is set on one of the thumb wheel switches so that a signal is sent to the sequence generator circuit at the end of paths like AB, CD, EF etc. for going to the next motion in the sequence. The width of the area to be scanned is set on the second thumb wheel switch so that a signal is sent to stop the stepper motors when scanning has been completed.

### 3.2 Present Set-Up

The popularity of the ultrasonic inspection system can be attributed to the wide applicability of the technique as well as its ability to locate and characterize various defects. The large amount of work regarding defect characterization, outlined in the literature survey, is possible mainly due to the detailed analysis of the received signal. However, use of GO-NOGO criteria for the ultrasonic C-scan plotting imposes a major

limitation. The significant data may be missed due to an improper setting of the threshold for GO-NOGO selection. The technique consisting of actual measurement of the received signal amplitude for C-scanning has proved to be versatile. It is the first step towards a more detailed signal analysis for damage identification and characterisation.

Another important requirement for Ultrasonic evaluation is collection and processing of a large amount of data. This work is time consuming, may introduce error, and therefore calls for automation. By interfacing the system with a microcomputer (PC-XT), it is possible to acquire , process and display the data using computer aids such as image processing.

Basically, Ultrasonic C-scan imaging requires the following information regarding flaw and position of the transducer :

i) Peak amplitude of the received signal,

ii) X & Y coordinates of the transducer location .

The main elements of the present set up are indicated in the block diagram in Fig. 3.4. The emitting probe is energized by a pulse from the ultrasonic flaw detector. The ultrasonic signal is passed through the test specimen and is collected at other end by the receiver probe. This signal is conditioned by the UFD and is fed to the peak detector circuit. The amplitude of the received signal is retained by the peak detector and is digitized by an analog - to -digital (A/D) converter. The digitized value of the peak amplitude is then transferred to the PC processor for

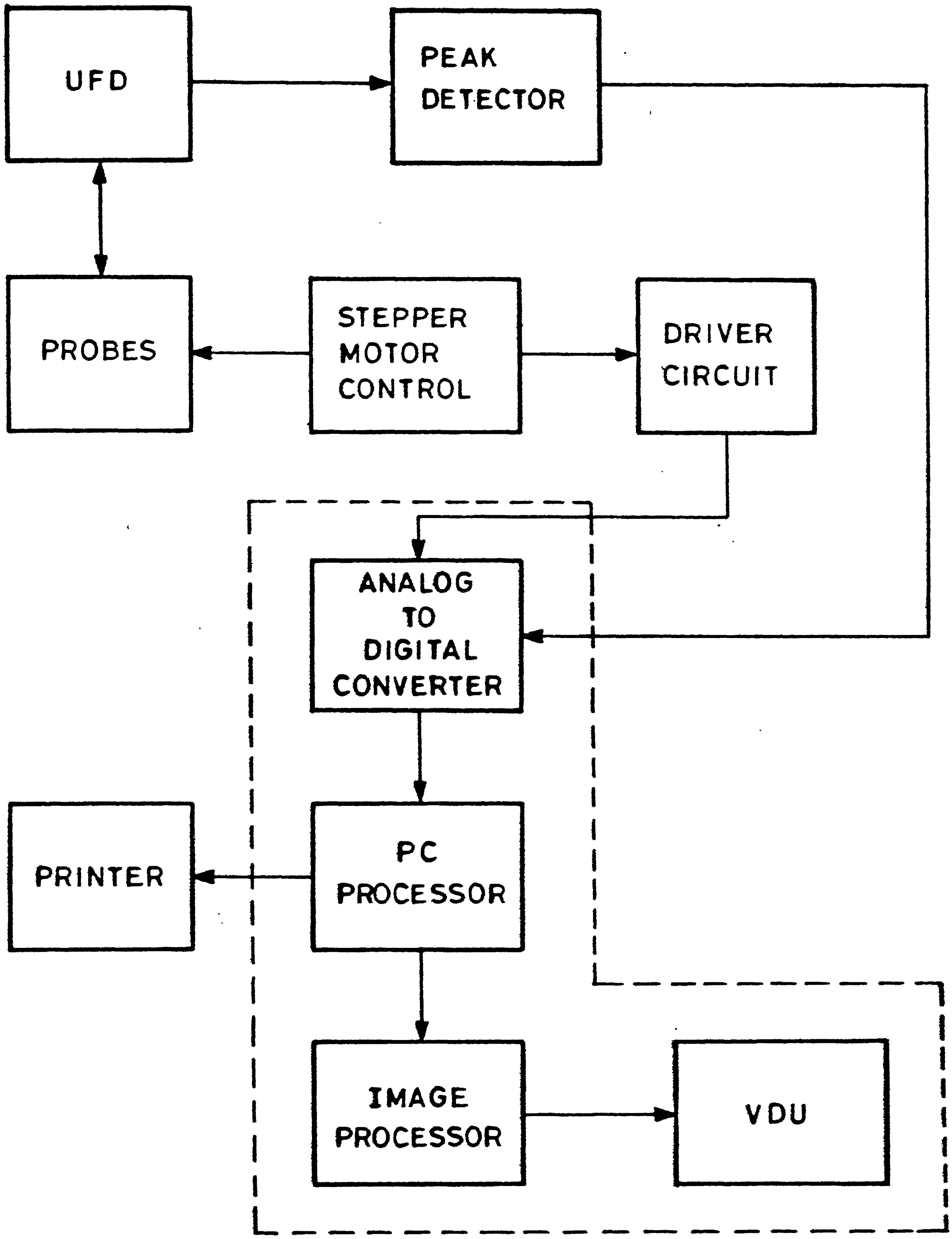



Fig.3.4 Present set up.

analysis. The other requirement is to transfer the data regarding the transducer location. The transducer motion is controlled by the stepper motor control circuit. Hence, this circuit is also interfaced with the PC processor through a driver circuit and an A/d converter . The acquired data is processed for visual representation using an image processing technique .

### 3.2.1 Interface for the received signal amplitude

The information regarding a flaw is contained in the received signal. However, this signal is very weak and contains noise as well. Therefore it is necessary to suppress the noise and amplify the signal. Filtration of signal is also required to remove the high frequencies and to get the signal envelope. The high quality signal conditioning circuits are required for satisfying these requirements. To make efficient use of the circuits, of available ultrasonic flaw detector (UFD 6255), it is necessary to keep track of the signal and the circuits modifying it.

Functional block diagram of the UFD along with voltage diagram at each stage is shown in Fig. 3.5 . The sweep unit generates the control signal for governing the rate at which the pulses are generated by the emitting transducer. This rate can be varied to suit the test specimen. Transmitter unit sends a pulse as soon as it receives a control signal from the sweep unit. The transducer gets excited and an ultrasonic signal is emitted. The signal is collected at the other end of the specimen and is fed to the amplifier. The amplifier unit contains pre-amplifier, high

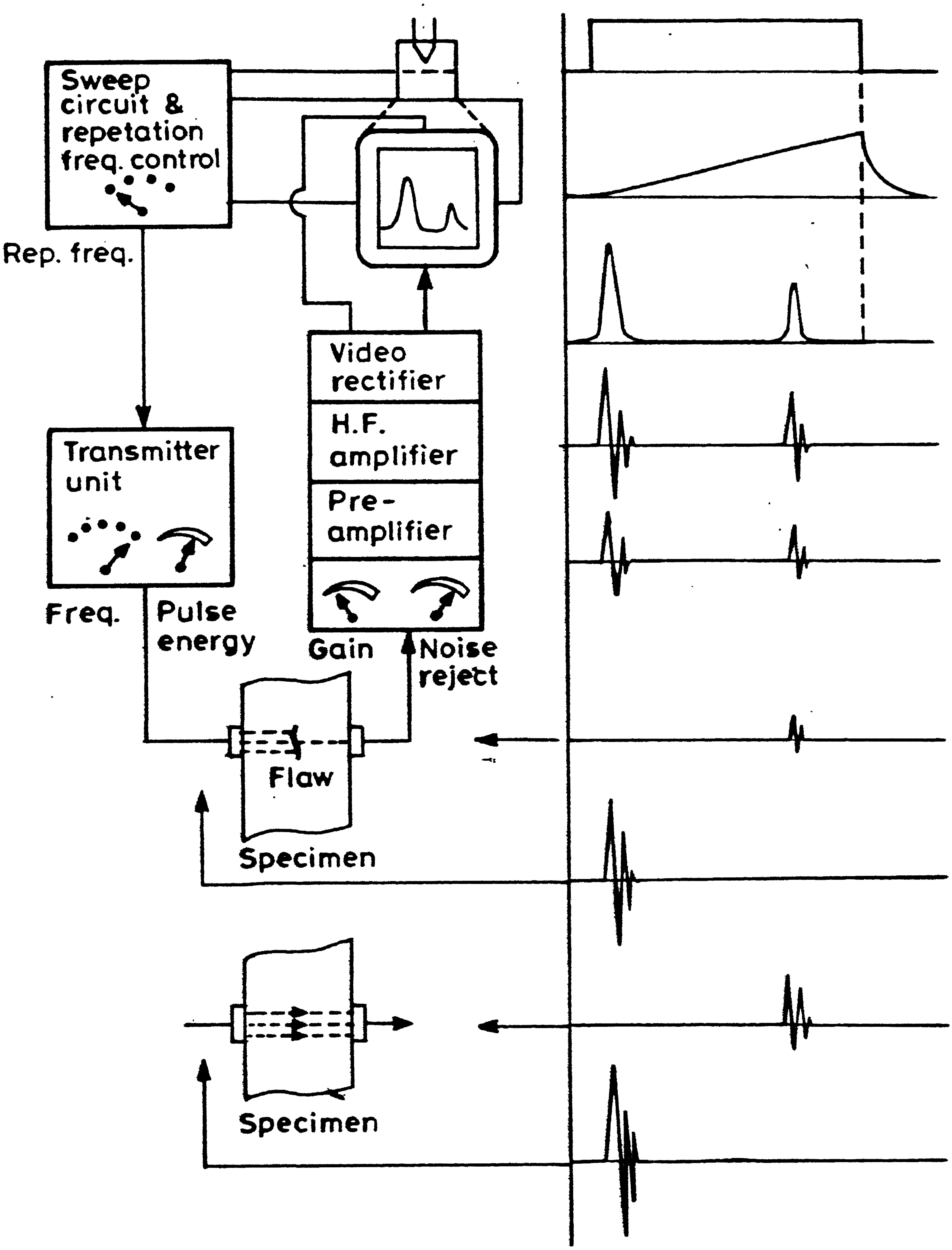



Fig.3.5 Ultrasonic flaw detector.

frequency ( HF ) amplifier and video rectifier stages. Pre-amplifier stage amplifies the signals, in order to lift them above the noise level. This is followed by a broad band HF amplifier stage covering all occurring ultrasonic frequencies from 1 to 10 MHz. The signal is then passed through video rectifier stage to get the signal envelope as shown in Fig. 3.5

vertical deflection plates of cathode ray tube.

It can be inferred from the above description that the output of the video rectifier provides a 'conditioned' signal suitable for digitization and further processing.

### 3.2.1.1 Peak Detector Circuit

As described earlier, the received signal is to be fed to a PC-XT for storing and processing the data. For this purpose an analog signal has to be converted into digital form. The digitization can be done by means of an analog-to-digital ( A/D ) converter as shown in Fig. 3.6 (a). The digitization process consists of converting a continuous signal into discrete signals at regular intervals. Magnitude of each signal is equal to the magnitude of the original continuous signal at the particular instant as shown in the Fig. 3.6 (a). To digitize an analog signal of time period (T) into n number of samples, sampling time ($T_s$) should be $1/n^{th}$ fraction of the signal time period (T). The accuracy of representing an analog signal in the digital form depends on the number of sample points. The accuracy increases as the number of sample points increase.

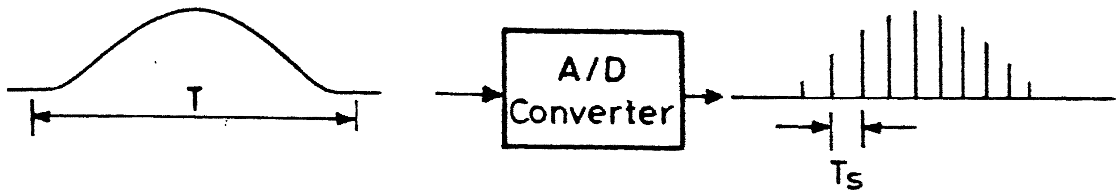



Fig. 3.6(a) Use of A/D converter.

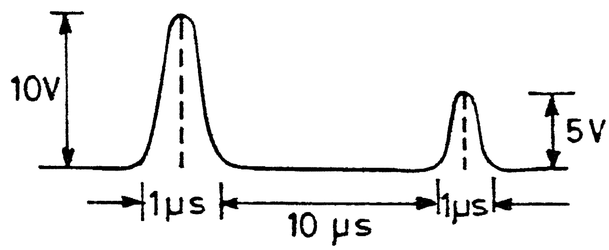



Fig.3.6(b) Video rectifier output waveform.

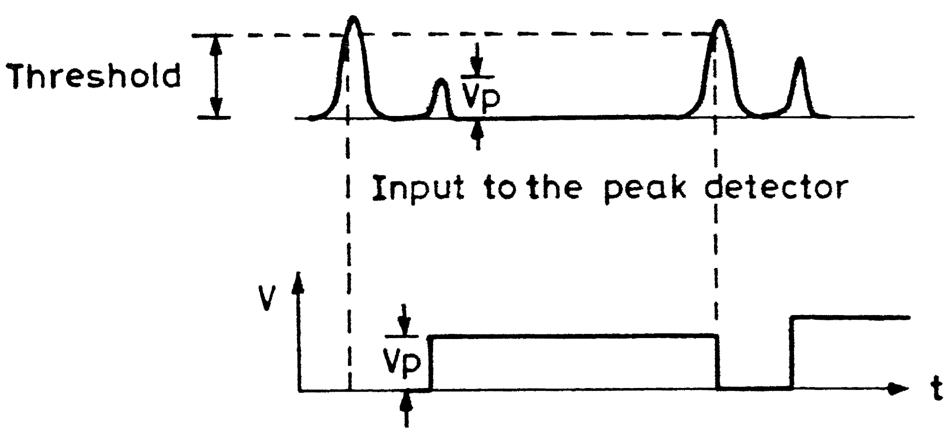
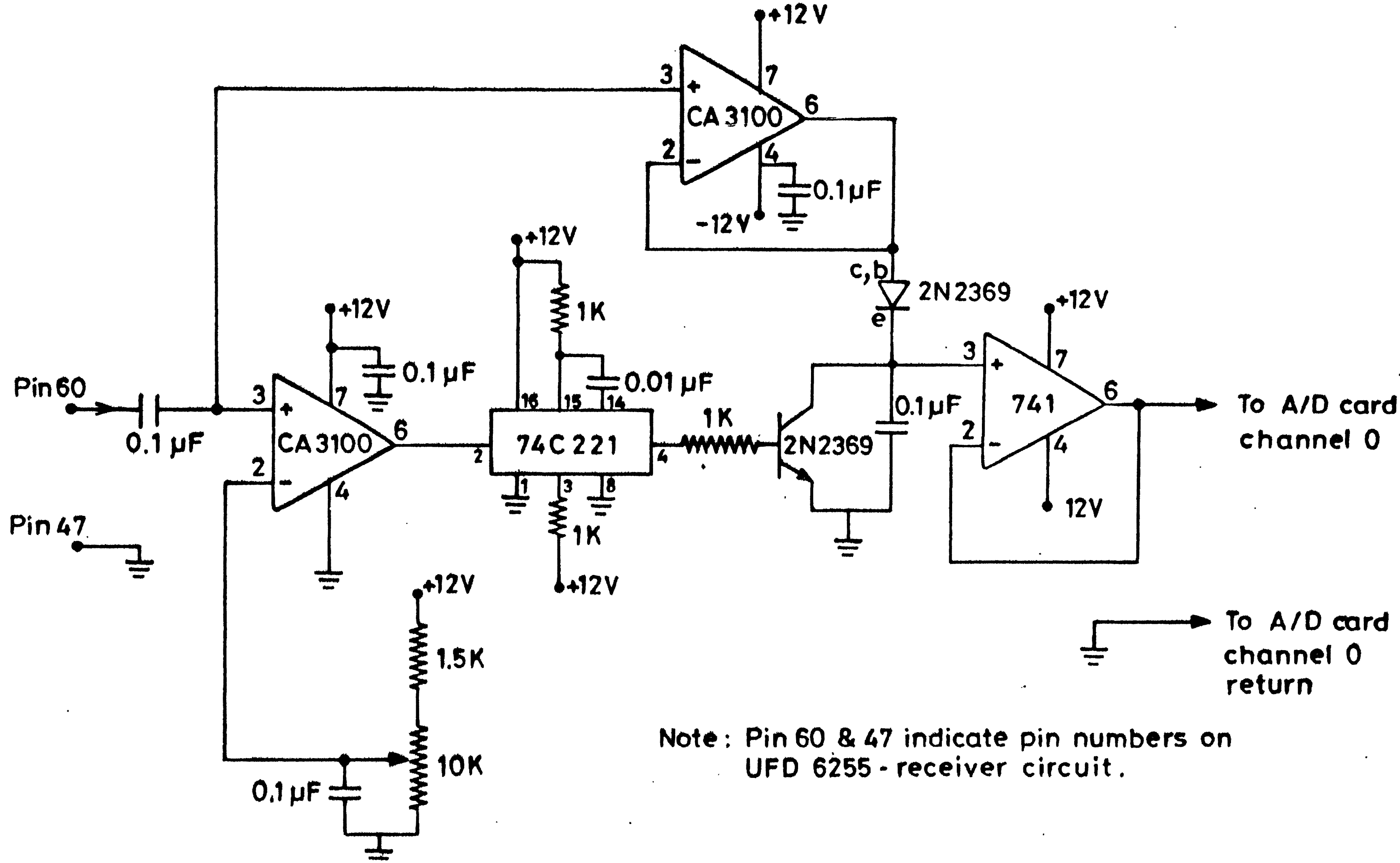



Fig.3.6(c) Input and output waveforms of the peak detector.

The wave form as it is available at the output of video rectifier stage is shown in the Fig. 3.6 (b) . It consists of emitted as well as received pulse. The width of the received signal is only 1 microsecond. Therefore, to obtain two samples of this signal, sampling time should be less than Ø.5 µS. The available A/D card ( DT-28Ø5 of Data Translation, 28Ø1 series), has a sampling time of Ø.66 milliseconds (sampling rate of 6.Ø KHz) . Hence, it is necessary to incorporate a circuit to detect peak amplitude of the received signal and then retain it till the next pulse arrives . Such peak detector circuit has been developed which provides the desired output as illustrated in Fig. 3.6 (c). With this type of signal, the available A/D card having a low sampling rates can be used. Design of the peak detector circuit is given in the following paragraphs.

**Design** : The waveform at the output of the video rectifier stage consists of emitted pulse as well as received pulse as shown in Fig. 3.6 (b) . The amplitude of the received signal is only to be picked, eliminating the emitted pulse.

The circuit diagram of peak detector is shown in Fig. 3.7. First stage, a buffer stage, is used for impedance matching. Operational amplifiers are selected on the basis of high slew rate requirements . The signal consisting of emitted as well as the received pulse is fed to a charging capacitor C1 (Ø.1 µF ) which gives the output signal proportional to the peak of the input voltage. This is short circuited to the ground at the instant when the emitted pulse arrives so that the output does not correspond to the emitted pulse. ( The peak voltage of the




Note : Pin 60 & 47 indicate pin numbers on UFD 6255 - receiver circuit.

Fig.3.7 Peak detector circuit.

emitted pulse is larger than the peak voltage of the received pulse. ) In fact the short circuiting is done by the signal produced by the emitted pulse itself. For this purpose a comparator amplifier is used which gives an output signal when the input signal voltage exceeds a threshold value. The threshold value is set lower than the peak voltage of the emitted pulse and higher than the expected maximum voltage of the received pulse. Thus, the comparator gives a signal when it receives a the emitted pulse. This signal is fed to the transistor acting as an analog switch through a multivibrator so that output of charging capacitor is proportional to the input voltage signal only after the emitted pulse has passed. Thus the output of capacitor is equal to the peak of the received signal as shown in fig 3.6 (c)

In the present case comparator input is set at 6 V so that the received signal below this value is detected and its amplitude value is latched.

### 3.2.2 Interface for Location Parameters

Location parameters include X and Y-coordinates of the transducers at the time of sampling . As described earlier, the specimen is scanned in a systematic path. The revolutions of the two stepper motors, controlling the transducer motion, are governed by a single clock circuit. Leadscrew coupled to the stepper motor shaft has 1 mm pitch. Hence, for 200 clock pulses transducer set moves by 1 mm. The proper choice of stepper motor controlling the X direction or Y direction is made to follow the

predetermined systematic path. Thus, by knowing the number of clock pulses passed, location of the transducer can be determined. In the present case, output of counter of the master control circuit is used for the purpose.

**Driver Circuit :**

The circuit used for stepper motor control is a transistor transistor logic (TTL) circuit that has limited driving current capacity. In the present set up, minimum possible distance between stepper motor control circuit and PC-XT is about two meters. Therefore it was not possible to drive the external trigger pulse over two to three meters of wire length by using the direct connection between TTL chip and A/D card. Thus, an additional driver circuit is incorporated to amplify the current to the required value. A simple and effective circuit as shown in the Fig. 3.8 is used in the present case. Two resistors act as current limiters.

### 3.2.3 A/D card and its use

For the present set up, an A/D card (DT-2805 of Data Translation, 2801 series ) is available for sampling the peak amplitude. Same card is also used for transferring the data indicating the location of the transducers.

The DT 2805 card is compatible with the available PC and can be plugged into one of the system expansion slots. In addition to analog to digital (A/D) conversions it can perform

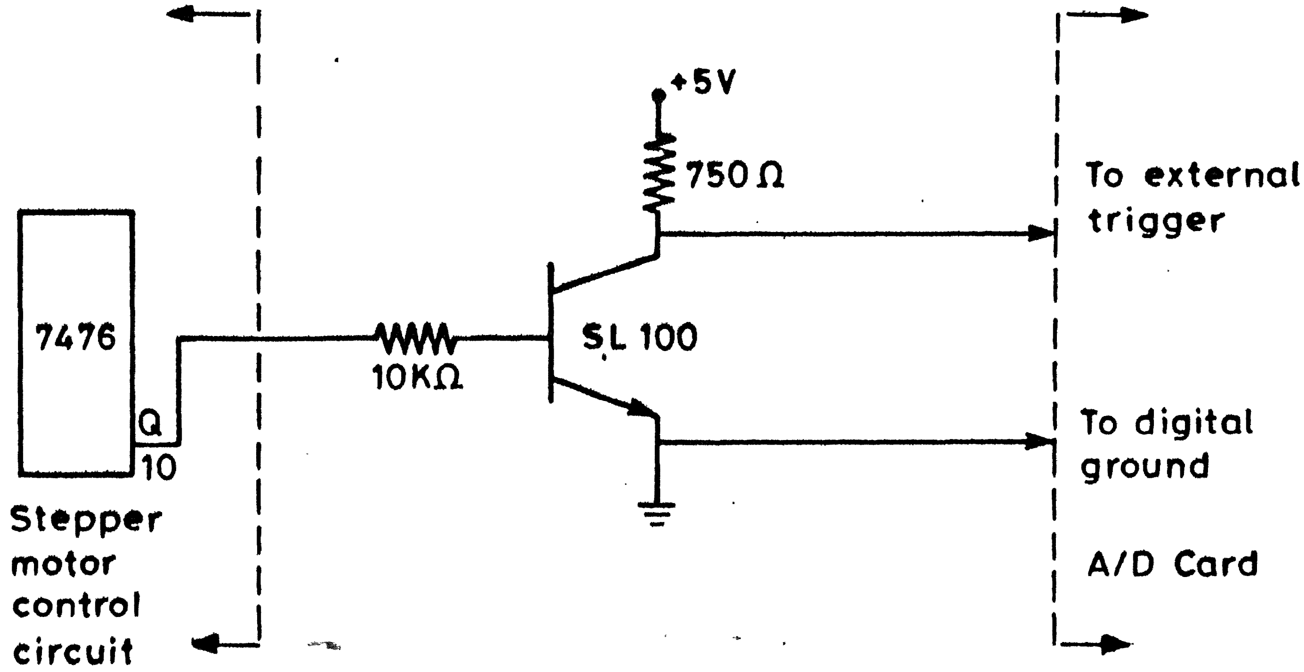



Fig. 3.8 Driver circuit.

digital to analog conversions and digital input and output transfers. The board also contains an on-board programmable clock, which can be used to provide clock pulse to control the operations of the board's A/D and D/A sub-systems.

Important specifications of DT -2805 card are as follows :

1) Resolution : 12 bits
2) Maximum A/D Throughput : 6000 samples/sec. using DMA
3) Droop rate : 0.1 mV/ms
4) Gain range : 1, 10, 100.

Technical specifications of the board are given in Appendix [A]. and further details regarding the functioning of the board are given in Users Manual [32].

In the present set up the receiver transducer receives signals continuously. However, they are digitized and stored at the fixed intervals of transducer movement (1 mm each time). To achieve this, the A/D card, which has the facility for external triggering, is triggered at the desired intervals by pulses produced by the clock generator . As explained in the earlier section, the location of transducers (x and Y coordinates can be determined from the knowledge of pulses sent by the clock circuit to the sequence generator circuit.

All connections for A/D card are made using DT-707 screw terminal panel. It is an accessory in which all the user connections of A/D card are brought out to screw terminal connectors. Further details are provided in Data Translation user manual [32].

### 3.2.4 Software for Data Transfer

The A/D card has an on board microprocessor and it can be programmed using software. Manipulation of bits in command register govern the operations of the board.

A software module in FORTRAN has been developed for the data transfer using PCLAB routines for manipulating the board operations. Detailed information regarding the operations of these routines can be obtained from user manual [33]. The program does following functions :

* To retrieve the data : Peak amplitude is sampled at each transducer position. Instead of taking a single sample at each transducer position, it is possible to take many samples and then averaging them in order to reduce the noise effect. In the present case, 21 sample points are taken at each location using 2KHz sampling frequency and then average value is selected. This value is also echoed on the PC monitor screen.
* To arrange the data : The transducers move from bottom right corner to upper left corner along a systematic path . While the image processor requires the data starting from upper left corner to lower right corner incrementing in positive X direction. The program rearranges the data to send it to the image processor.
* It stores the data in a user selectable file.

The flow diagram of this software is shown in Fig. 3.9.

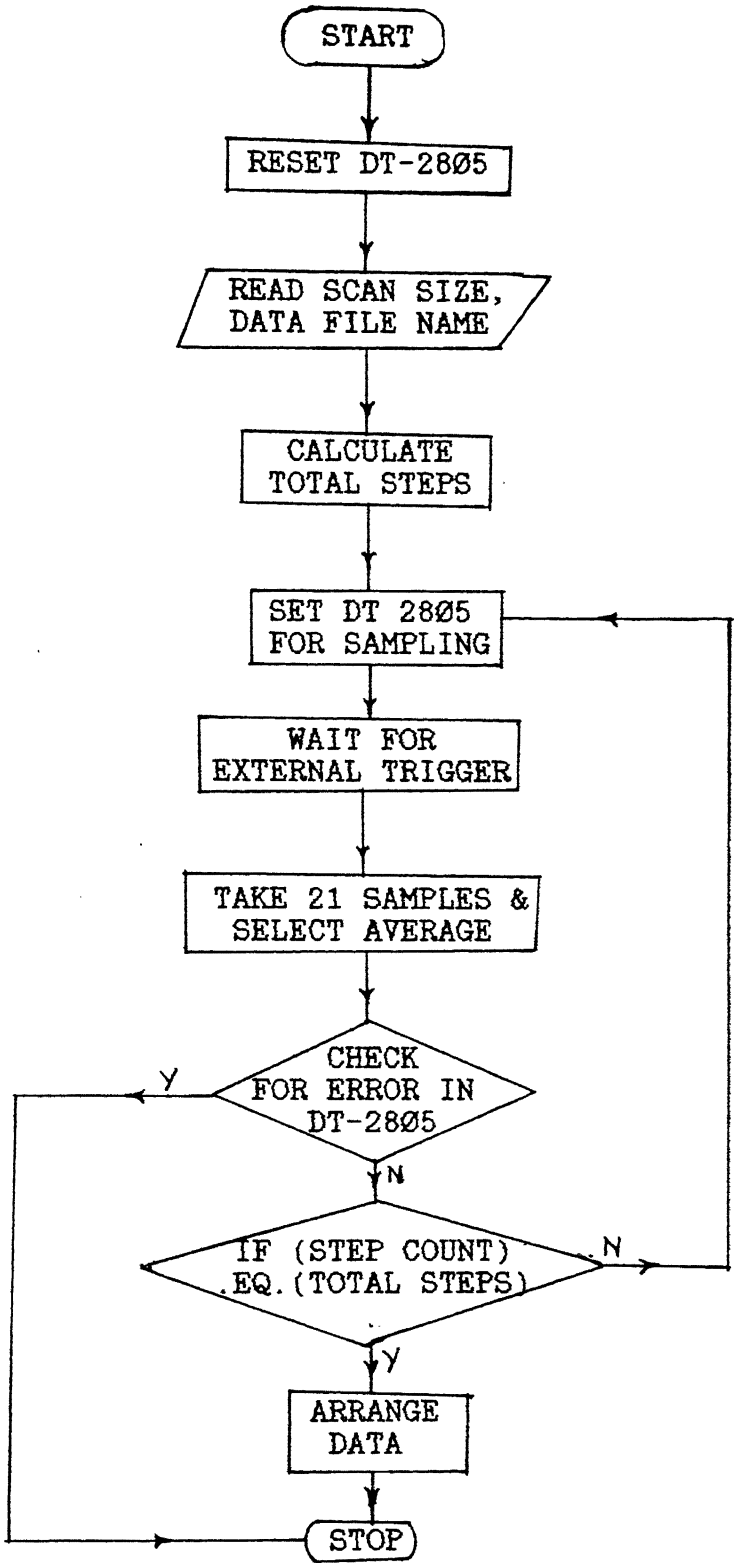



**Fig. 3.9 Flow diagram for data transfer software**

### 3.2.5 Image Processing

#### 3.2.5.1 Introduction

The common functional requirement of any Ultrasonic inspection system is representing the acquired data in the form of maps. The data can be displayed in several convenient forms, such as A-scan, B-scan, C-scan . The data presented in these forms can be interpreted for the possible presence of defects, their location and the size. A computer can play a major role in automating this defect detection by employing various computer aids for data analysis. Image processing is an important aid in effectively representing the significant data and in suppressing the insignificant one.

Image processing is the tool which provides a graphic representation of an image. It deals with quantitative as well as qualitative features of the image. Digital image processing technique involves digitizing a picture and then manipulating it to enhance its significant aspects. A picture is digitized by first dividing it into discrete cells called pixels. Brightness or intensity is assigned a number for later mathematical manipulation . The intensity distribution and frequency of occurrence of each intensity for the given picture are obtained and represented statistically as a **histogram** . Figure 3.10 shows a picture and the corresponding histogram. The manipulation of the digitized image involves modifying the intensity of pixels. The pixel intensity can be modified using a mapping function. Probably the simplest manipulation involves

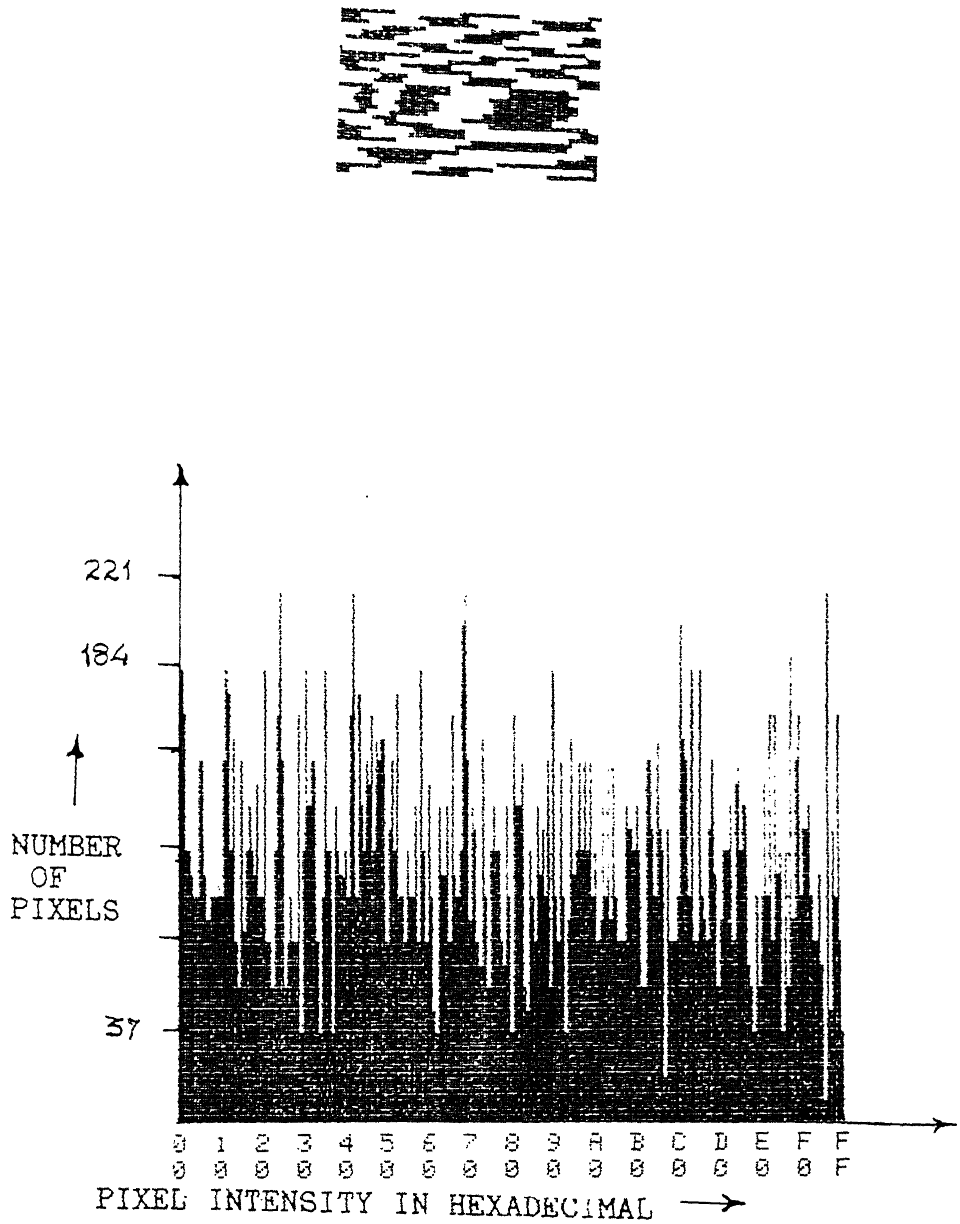



Fig. 3.10 Image and corresponding histogram

dividing all the pixels into two groups, one with intensity level above a threshold value while the other with that below the threshold value. The threshold value of the picture is selected by considering the intensity distribution of complete picture. This method is, therefore, called the **global thresholding**. Considering the effect of neighbourhood of the pixel is another technique for processing the image. In this technique, pixel intensity value is modified by considering the intensities of the neighbouring pixels through a weighting function. Various manipulations are possible depending upon the weighting function used . The technique which involves taking an average of neighbouring pixel intensities with all the weights equal to unity, is called **averaging** .

### 3.2.5.2 Pseudo Colouring

Pixel intensity data are generally stored in 8 bit registers. Hence 256 ( $2$ )$^8$ grey levels can be indicated. The gray levels can be arbitarily assigned different colours in case a colour video monitor is used. Actual colour is obtained by combining three basic colours : Blue , red and green. Each of these colours can have 256 brightness levels independently. Thus a total of $(256)^3$ colour values are possible. However, in the present case only seven colour combinations have been used. Table 3.1 shows the combinations of basic colours with their brightness levels required to attain these seven colours.

| COLOUR | RED LUT | GREEN LUT | BLUE LUT |
|---|---|---|---|
| RED | 255 | Ø | Ø |
| GREEN | Ø | 255 | Ø |
| BLUE | Ø | Ø | 255 |
| YELLOW | 255 | 255 | Ø |
| CYAN | Ø | 255 | 255 |
| MAGNETA | 255 | Ø | 255 |
| WHITE | 255 | 255 | 255 |
| ITBLUE | Ø | Ø | 127 |
| BLACK | Ø | Ø | Ø |

Table 3.1 Pseudo Colouring

### 3.2.5.3 Image Processing Board

The PC is fitted with an image processing board ( Matrox Image Processing [PIP- 1024 B] ) which is used for displaying the stored ultrasonic data on a colour monitor. It is a plug-in board compatible with the PC-XT . Video data can be written on frame buffer memory of the image processing board from PC's memory. Various board functions can be controlled by software. Technical specifications as well as software details can be obtained from reference manual [34].

A software in FORTRAN was developed for showing the imaging of the acquired ultrasonic data. PIP subroutines are used to control the board functions. The flow diagram of this software is shown in Fig. 3.11. It's functions are summarized below.

* Image file Creation : Data in real or integer form is converted into ASCII form and an image file of the ultrasonic data is created. The image processing card uses this file for displaying the image.

* Zooming : It calculates the permissible range of zooming for the given image. User can select any zooming factor in this range.

* Pseudo colouring :For easy location and interpretation of the defect, pseudo colouring is done. Four colours are selected for enhancing the contrast. Colour scale is also provided to get an approximate peak amplitude.

* Dilated image : Optional facility for eroded or dilated images

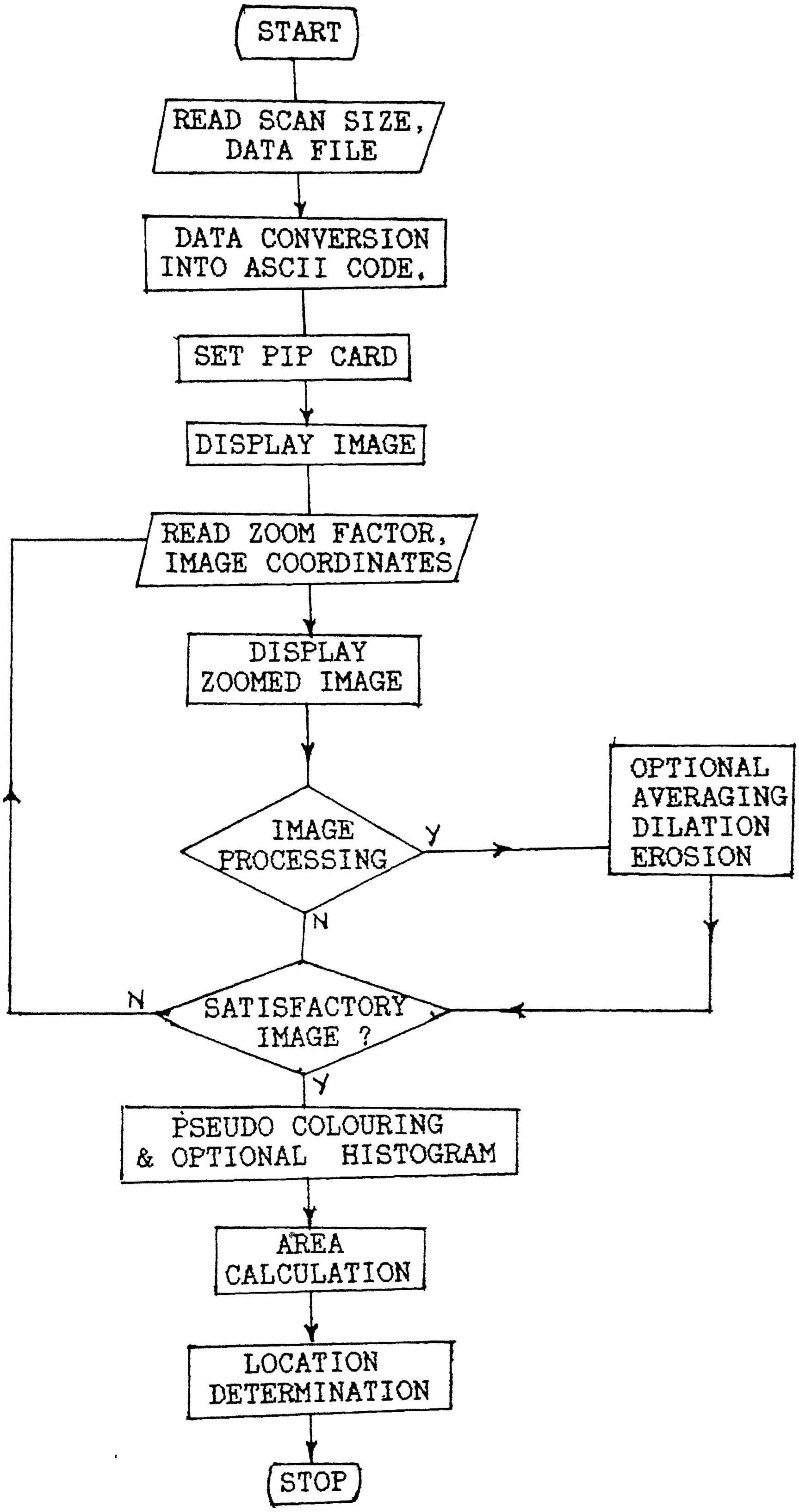



**Fig. 3.11 Flow diagram of image procesing software**

is provided.

* Histogram : It is plotted at the bottom right corner of the screen. The histogram can be useful for selecting a threshold to create a binary image.

* Defect Location : The coordinates of any pixel and corresponding intensity value can be obtained just by bringing curser on the required location. This facilitates defect sizing. Selected values can be stored in the file for documentation purpose.

* Area calculation : The area of chosen damage zone is calculated.

# CHAPTER 4
# RESULTS AND DISCUSSION

The success of any developmental work depends on the satisfactory performance of the system in its end use. The present system is developed to provide a facility for the ultrasonic C-scan image of composite specimens. Prime importance is given to ease of detection and accuracy in determining the size of the flaws. The performance of the system developed is evaluated by testing the composite specimens with ? artificially introduced flaws and the specimens damaged by impact loading.

## 4.1 Calibration

In order to obtain an accurate and reliable C-scan, it is necessary to set testing parameters for the ultrasonic inspection system. In the present system , the peak detector is designed such that the received signal amplitude is detected when it is below a certain value ( i.e. less than 6 V ). This can be achieved by adjusting the gain setting of the ultrasonic flaw detector such that the trace of the received signal peak is always visible on the CRT screen. The sequence to be followed while switching on the system is given in Appendix [ C ].

All the tests were conducted with 2.5 MHz straight beam contact type probes of 12 mm. diameter. As described earlier in section 3.4, to minimize the noise, twenty one samples of peak amplitude are acquired at each location and their average value is used for the analysis.

### 4.1.1 Accuracy Test

To evaluate the accuracy and overall soundness of the system a mild steel specimen of 5 mm thickness with a circular hole of 16 mm diameter was scanned. The specimen and the corresponding Ultrasonic C-scan image are shown in Fig. 4.1 . Each pixel represents 1 $mm^2$ specimen . The corresponding image is shown in a rectangle. As it is small and inconvenient to analyse, zooming facility is provided. The zoomed image with 5 times zooming is shown in the figure. Diameter of the hole as indicated in the displayed C-scan image is measured using the interactive feature of the program. This value was compared with the actual dimension. It is observed that the hole diameter obtained through the C-scan is within 6 % of the actual value.

The system was next tested for the specimen made of composite material with a square hole acting as an artificially introduced flaw.

The test specimen is prepared using woven glass fiber prepregs ($0/90^o$ orientation, equal number of fibers in both directions). A square hole of the required dimensions was cut from each lamina and ten laminae were stacked over each other to form the test laminate. The thickness after curing is 1.8 mm and fiber volume fraction is 45 % .The curing procedure is mentioned below.

Pressure of 100 p.s.i. was applied at room temperature and at this pressure the uncured laminate was heated gradually.

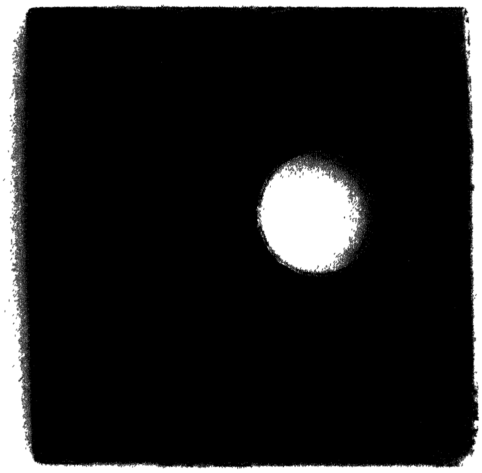


Fig. 4.1 A mild steel test specimen.

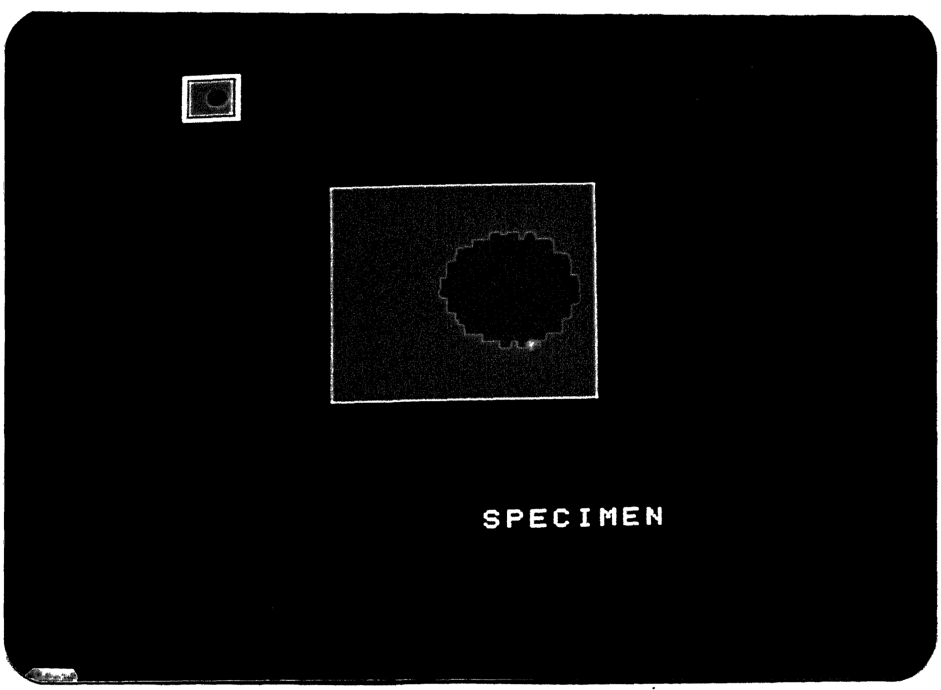



Fig. 4.1 Ultrasonic C-scan image of the specimen.
Actual image, 5 times zoomed image

At $150^{\circ}$ C, the pressure was increased to 250 p.s.i. and the laminate was held at this temperature and pressure for 2 hours. Then the temperature and pressure were decreased slowly to complete the curing. The cured glass fiber laminate was cut to the size and the epoxy spread in the hole was trimmed off by filing.

Figure 4.2 (a) shows the test specimen. The C-scan image of the specimen is shown in Fig. 4.2 (b) . For displaying the variation in the received signal amplitude, Different colours are used. Each colour represents a range of the received signal amplitude. The top right corner indicates the colouring scheme used. The value obtained from the colour scale devided by 10 gives the peak amplitude of received signal in volts.

The area of the flaw was measured from the C-scan image using interactive feature for area calculation. This value was compared with the actual value. The difference in the two values is 5 % . Inaccuracies in the flaw are due to the limitations of transducer diameter and frequency. More accurate results can be obtained by their proper choice .



## 4.2 Impact Damaged Specimen Testing

For studying the failure mechanisms in composite specimens subjected to destructive tests, the accurate determination of the location of the damage and its size is of prime importance. Prashant Kumar [35] conducted the impact tests for analysing the behaviour of composites subjected to impact loading. The

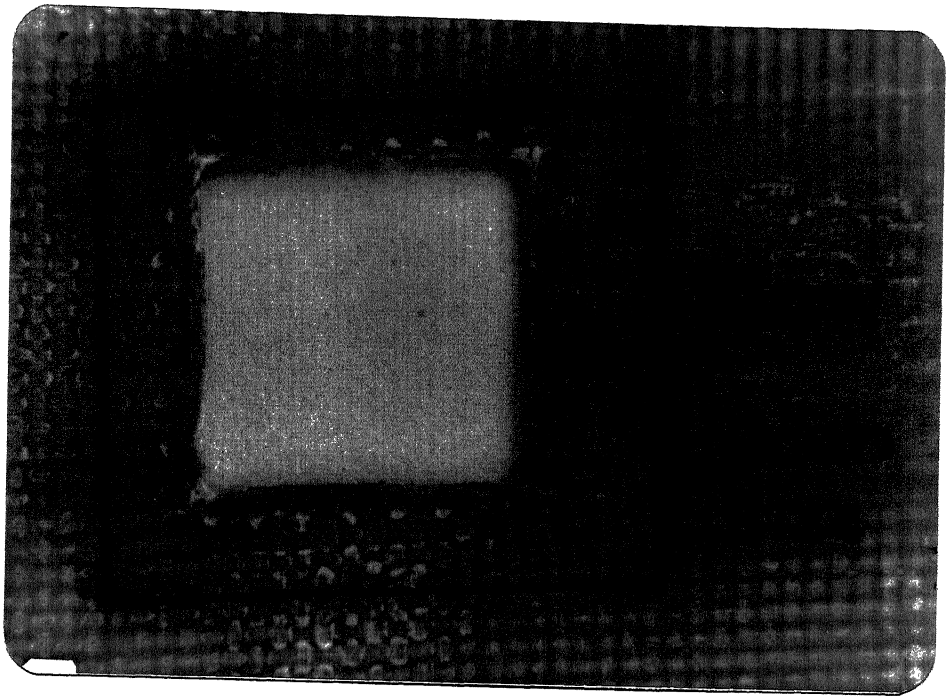


Fig. 4.2 (a)  Composite specimen with artificial flaw.

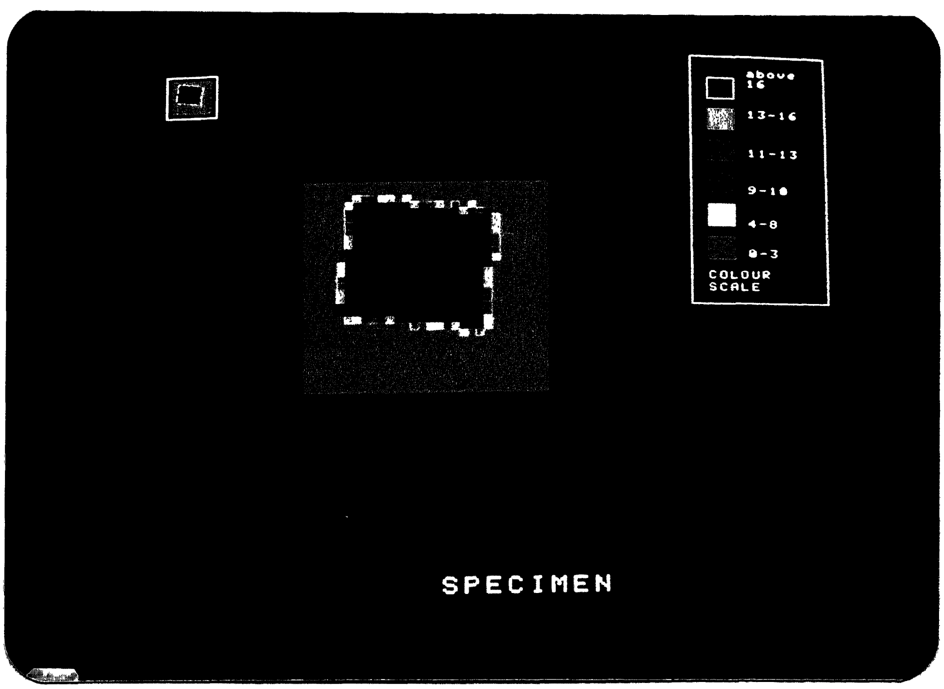



Fig. 4.2 (b)  C-scan image with pseudo colouring . Actual image, 9 times zoomed image with colour scale.

specimens include Kevlar fibre composites and glass fibre composites. The glass fibre specimen was having 16 layers ( [Ø2/9Ø/Ø2/9Ø]s ) and Kevlar fibre specimen was having 12 layers ([Ø/9Ø]). The composite panel was subjected to impact load by striking it with a rounded nose steel projectile. The damage due to the impact was observed visually by holding the specimen against bright light and then marking the contour of the damage zone which is opaque due to the dispersion and refraction of the light waves in the damaged area . The damaged area was measured with planimeter and the effect of velocity of the projectile on the size of the damage has been studied. The same composite specimens are examined using the present set up.

Figure 4.3 (a) shows a Kevlar fibre composite laminate impacted by a projectile with velocity of 35 m/s . The marking indicates the contour of the damaged zone identified by visual inspection. The ultrasonic C-scan image of the test specimen is shown in Fig. 4.3 (b). The following features can be noted regarding the image presented in the figure,

1) The range of the received signal amplitude and the frequency of occurrence of each value is represented by the histogram which is shown in the right bottom corner of the figure.

2) The zoomed image with 9 times zooming can be seen which is convenient for analysis. Various contours can be easily distinguished due to the pseudo colouring. The fall in the value of the peak amplitude of the received signal indicates the presence of the flaw in an otherwise undamaged specimen.

3) The coordinates and intensity value of any pixel can be obtained by bringing a cursor to the required position. This

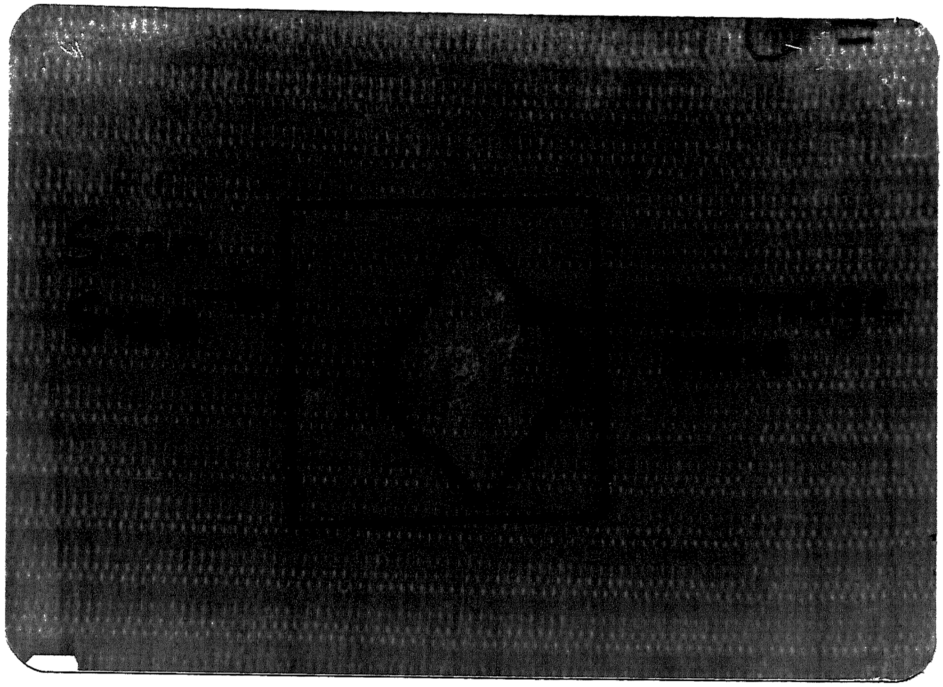


Fig. 4.3 (a) Kevlar/Epoxy composite .
Projectile velocity =35 m/s

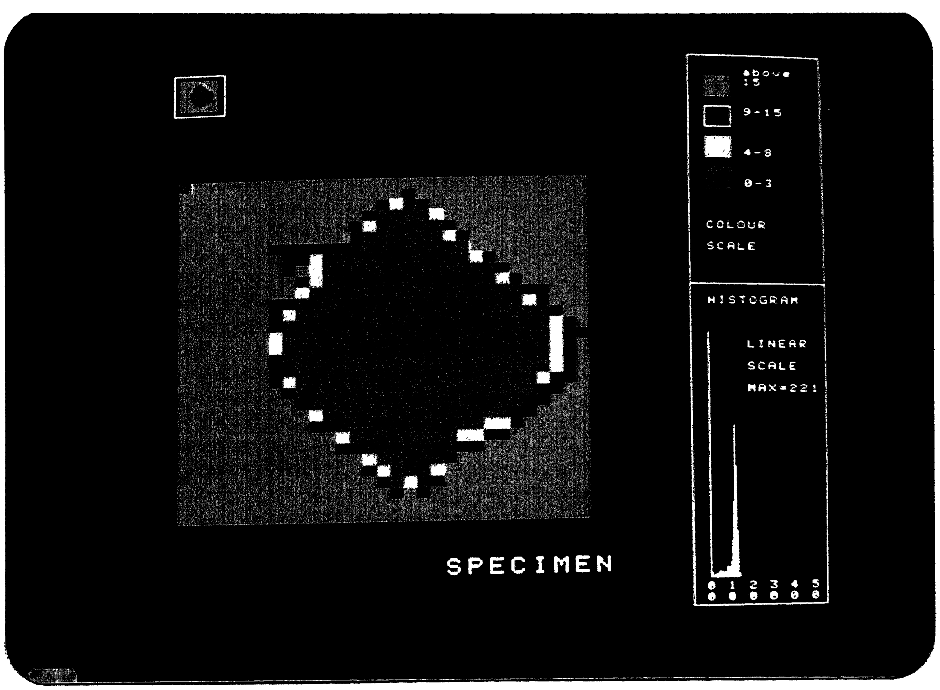



Fig. 4.3 (b) C-scan image with histogram .
Actual image, 9 times zoomed image

makes the damage location and sizing very easy.

4) The area of the chosen damaged zone can be automatically calculated, improving the accuracy and eliminating the tedium in using the planimeter. The chosen data can be stored in the file for further use.

The area of the damage region obtained from C - scan matches, within 4 % of that obtained by visual examination. This shows the accuracy of the present set up.

Figure 4.4 (a) shows a Kevlar fibre reinforced composite specimen impacted by a projectile moving with a velocity of 40 m/s . The ultrasonic C-scan image and it's eroded version are displayed in Fig. 4.4 (b). It can be seen that the noise is reduced in the eroded view. The damaged area can be easily identified . Red colour represents the complete attenuation of the emitted signal i.e. the peak amplitude of the received signal is zero. It can be noted that the damage contour displayed by the C-scan image conforms with the contour obtained by visual inspection. The difference in the areas obtained by two methods is 7 %. The amplitude analysis of the received signal permits marking of the various contours in the image, depending on the extent of damage. Thus, use of this technique in analysing the behaviour of composite specimens subjected to destructive tests can be appreciated.

A Kevlar fibre composite specimen shown in Fig.4.5 (a) was subjected to impact of projectile with a velocity 69.1 m/s. The corresponding ultrasonic C-scan is shown in Fig. 4.5 (b) .

It can be clearly seen that the displayed damage zone

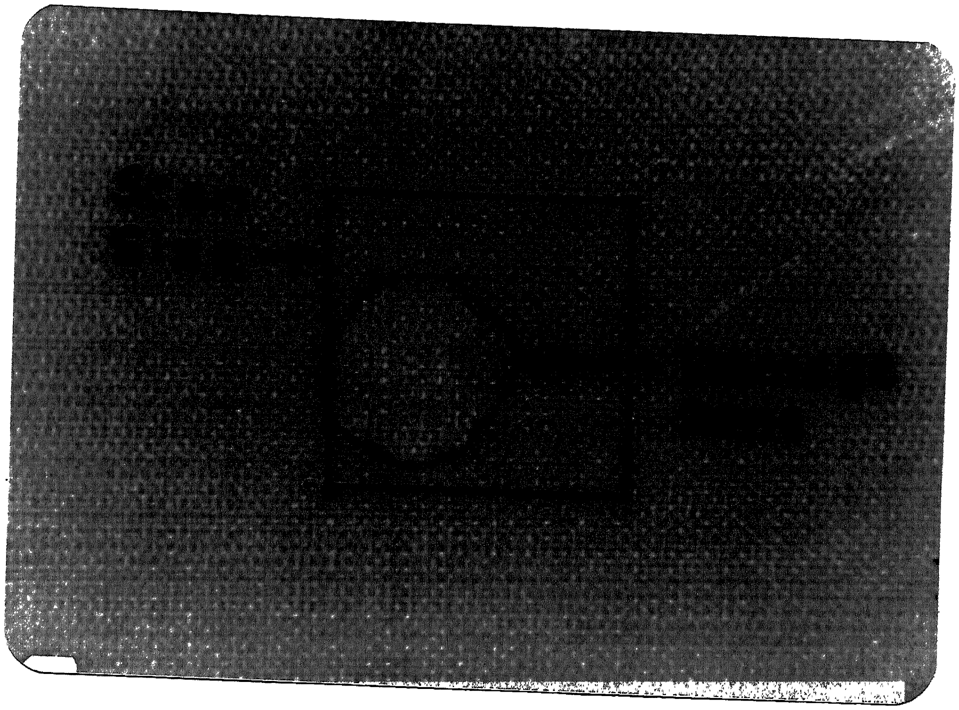


Fig. 4.4 (a) Kevlar/Epoxy composite .
Projectile velocity =40 m/s

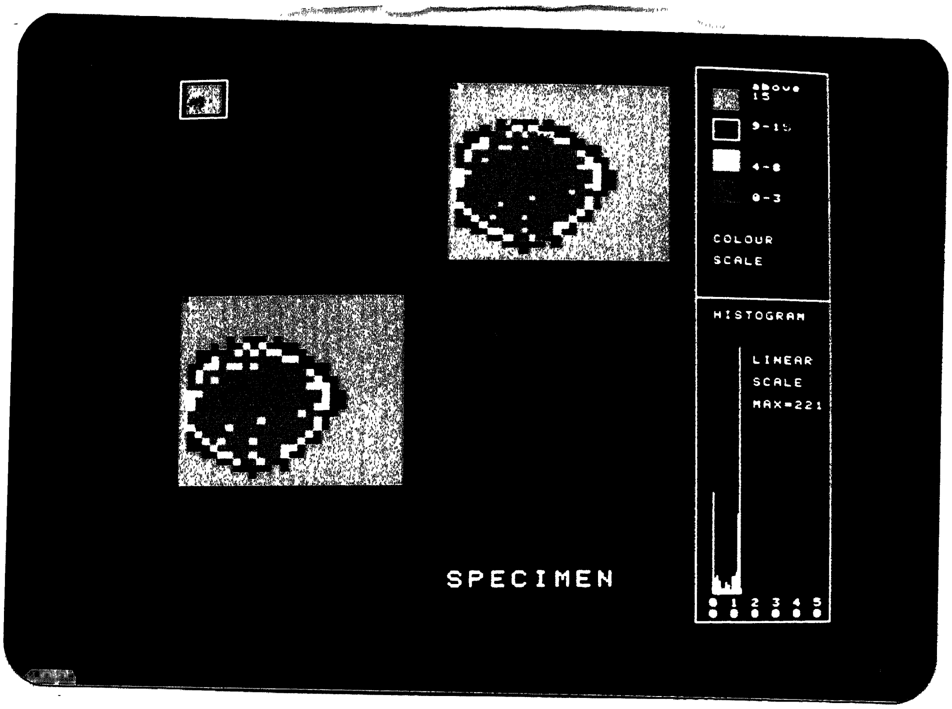
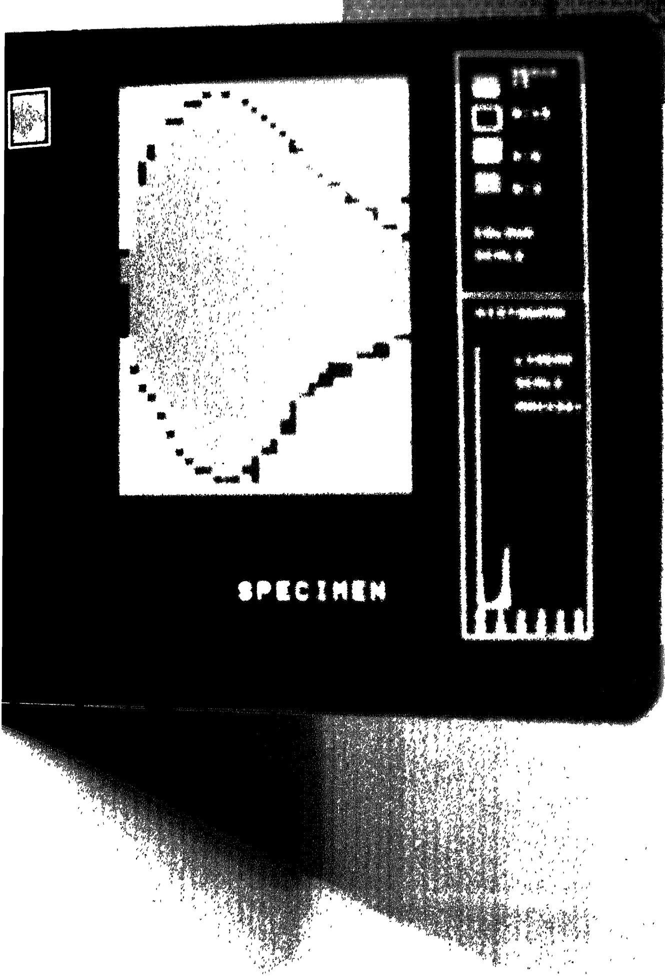



Fig. 4.4 (b) C-scan image :
Actual image, 9 times zoomed image,
eroded image .




Kevlar/Epoxy composite .
Projectile velocity =69.1 m/s

Fig. 4.5 (b) C-scan image :
Actual image, 9 times zoomed image.

matches well with that obtained from visual examination. There is 4.5 % difference in the areas obtained by the two techniques.

The increase in size of the damage with increase in projectile velocity can be noted from these results.

Figure 4.6 (a) shows a glass fibre specimen impact damaged by a projectile with velocity of 1Ø4 m/s .

The C-scan binary image is presented in Fig. 4.6 (b) . For displaying this image, pixels are grouped in two categories : one containing pixels of value below the set threshold while other containing pixels above the threshold. Thus, there are only two colour levels representing two peak amplitude values. The histogram also attests the binary image. The threshold value was set at 1 volts at the time time of data collection. In some cases thresholding can be very useful for noise elimination and better contrast and thus giving clear indication of the flaw contour. In the present case the red colour represents zero value of the received signal indicating the presence of the flaw. It can also be observed that the present system is capable of exploring the damaged areas which could not be detected by visual inspection technique.

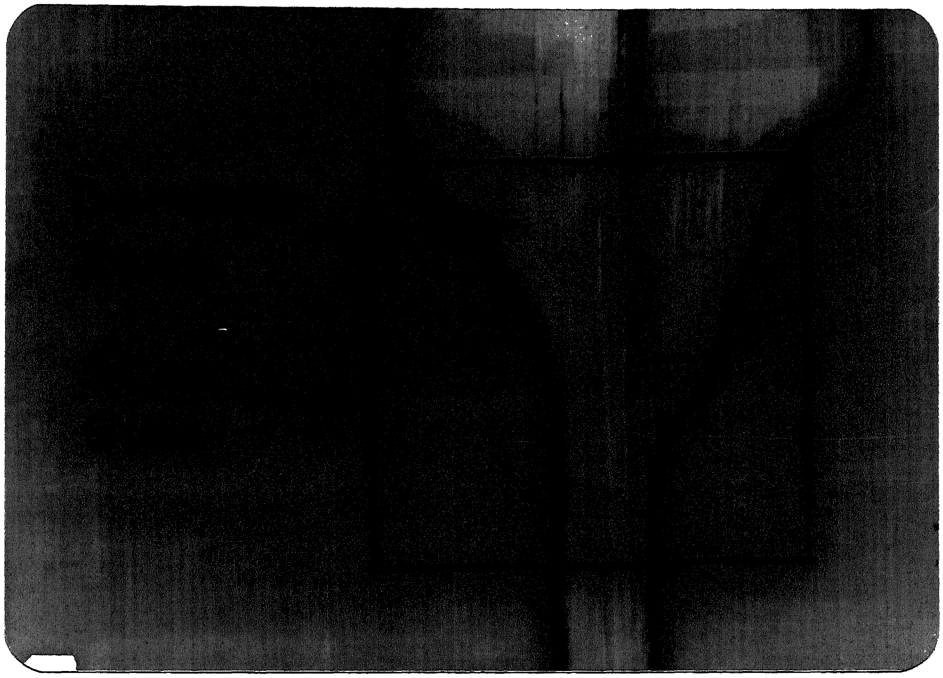


Fig. 4.6 (a) Glass/Epoxy composite .
Projectile velocity =1Ø4 m/s

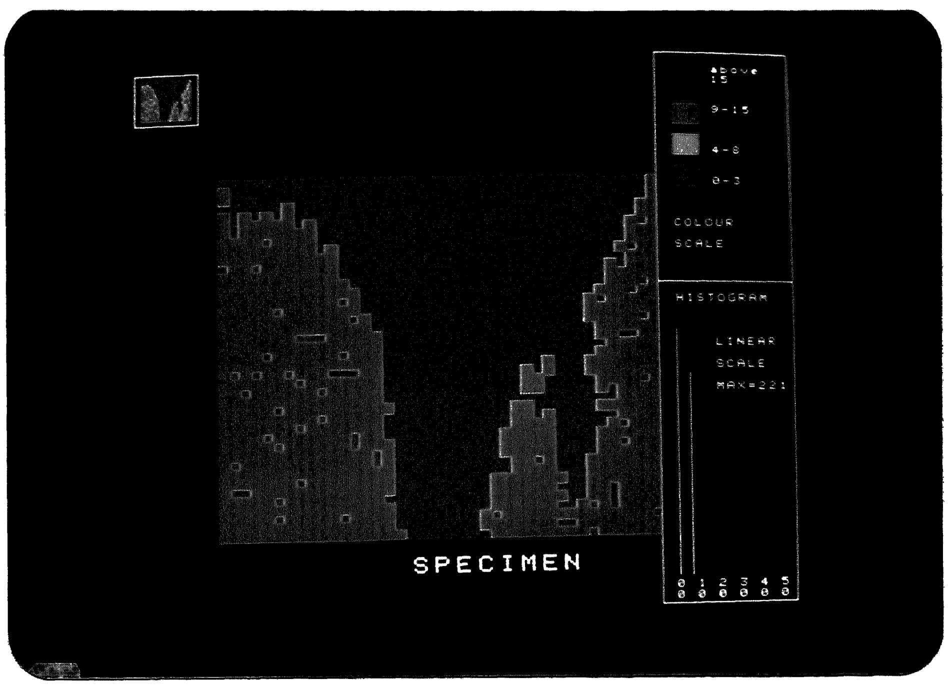



Fig. 4.6 (b) C-scan image :
Actual image, 9 times zoomed binary image .

## CHAPTER 5

## CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

### 5.1 Conclusions

In the present work, a PC-XT based ultrasonic inspection system was developed using an available mechanized scanner to generate C-scan images based on received signal amplitude. For this purpose, an ultrasonic flaw detector and scanning set up were interfaced with a PC-XT through an A/D converter. The peak detector circuit and the necessary circuits for interfacing were developed. For displaying C-scan images indicating the damage zones, capabilities of the image processing card were utilized. The ultrasonic data is displayed by showing flaw contours with various colours. calculating the damage area.

The system was calibrated for Glass fiber and Kevlar fiber composites. A composite laminate with an artificially introduced flaw was tested using present set up. Various specimens subjected to different impact loads were also evaluated for detection of the flaws and determination of their areas.

From the results discussed in Chapter 4, it can be concluded that, the present set up can be effectively used for the detection of flaws. It facilitates ease in location and sizing of damages due to the interface of system with a computer. The system can be employed to determine the effect and growth of flaws and for the analysis of failures in the composite specimens

subjected to destructive tests.

## 5.2 Suggestions for future work

The following areas can be identified for enhancing the capabilities of the present system.

i) To introduce more flexibility in scanning , the mechanism can be automated using stepper motor control cards monitored by PC - processor

ii) A more sophasticated ultrasonic flaw detector can be employed for more accurate results and to detect the depth of the flaws in the specimen using more sophisticated ultrasonic flaw detector.

iii) The detailed analysis of the received signal can be done for the characterization of the flaws. Using fast A/D card for sampling and signal analysis, it is possible to get more information regarding the flaw.

## REFERENCES


1. Arrigton, M., 'Non destructive testing of fiber reinforced composites', Vol.1, Elsiver Applied science, London, 1987, pp 125-39.

2. Belchamber, R.M., Betteridge, D., 'Looking for the patterns in the acoustic emission from reinforced composites', SPI ,San Francisco, July 1983, pp 1-5.

3. Hagemaier, D.J., 'Non destructive testing of advanced composites', Material Evaluation, Vol. 37, 1979, pp 43- 49.

4. Burch, S.F., 'Computer assisted real time radiography', NDT Centre, AERE, Harewell, U.K., 1982.

5. Melaughlin, P.V., 'Non destructive examination of fiber composite structure by thermal field techniques', NDT International, Vol. 13, April 1980, pp 56-62.

6. Colin, A., Walker, J., Mckelvie, 'Optical methods : Non destructive testing of fiber reinforced composites', Vol. 1, Elsiver Applied Science, London, 1987.

7. Firestone, F. A.,'Supersonic reflactoscope, an instrument for inspecting the interior of solid parts by means of sound waves ',J.A.S.A.,Vol.17,1942,pp287-299

8. Krautkramer, J. and Krautkramer, H., 'Ultrasonic testing of materials' 2nd edition, Springer-Verlag, Berlin, 1977.

9 Rose, J.L., 'Ultrasonic wave propagation principles in composite material inspection', Materials Evaluation, Vol. 48, 1985, pp 481-483.

10. Nevadunsky, J.J. and Lucas, J.J., 'Early fatigue damage location in composite materials' - Journal of composite materials, Vol.9, Oct. 1975, pp 394-408.

11. Mahoon, A., 'Non destructive testing of aircraft composite structures', Proceedings of the international conference on testing, evaluation and quality control of the composites, Butterworth and company, Kent, 1983, pp 93-101.

12. Prakash, R., 'Non destructive testing of composites', Composites, October 1980, pp 217-224.

13. Scott, I.G. and Scala C.M., 'A review of non destructive testing of composite materials, NDT International, April 1982, pp 75-86.

14. Speakes, J.H. and Arridge, R.G.C., 'Measurement of the cure of the resins by ultrasonic techniques' - Journal of Applied Physics, Vol. 7, 1974, pp 412-424.

15. Lindorse, A.M., 'Ultrasonic wave changes in curing of epoxy resin - Experimental Mechanics', 1978, pp 227-232.

16. Rose, J.L. and Carson, M. , 'Ultrasonic Non Destructive test procedure for the early detection of fatigue damage and the prediction of remaining life' - Materials Evaluation, Apr. 1980, pp 27-34.

17. Harris, B., ' Assessment of structural integrity of composites by Non Destructive methods', paper published by the school of Materials Science, University of Bath, U.K., pp 22.

18. Reynolds, W.N. and Wilkinson, J.H., 'The analysis of fibre reinforced porous composite materials by measurement of Ultrasonic velocities' - Ultrasonics, Vol. 16, 1978, pp 159-163.

19. Kaelble, D.H. and Dynes, P.J., ' Methods for detecting moisture degradation in graphite epoxy composites' - Materials Evaluation, Vol. 35, 1977, pp 103-108.

20. Bar-Cohen, Y.,'NDT of fibre reinforced composite materials - a review' - Materials Evaluation, Vol. 44, 1986, pp 446-454.

21. Moran, T.J., Crane, R.L., 'High resolution imaging of microcracks in composites' - Materials evaluation, Vol. 43, 1983, pp 536-540.

22. Cousins, R.R. and Markham, M.F., 'The use of Ultrasonic spectroscopy in the location of delamination in fibre reinforced polymers', - Composites, July 1977, pp 145-152.

23. Gericke, O.R., Monagle, B.L., 'Determination of delaminations by Ultrasonic spectroscopy', IEEE Transactions on sonics and Ultrasonics, 1976, pp 339-345.

24. Rose, J.L., 'Elements of a feature based Ultrasonic inspection system', - Materials Evaluation, Vol. 42, 1984, pp 210-226.

25. Rose, J.L., Bhashyam, M., Subramanian, K., 'Physically based Ultrasonic feature mapping for anomaly classification', - Materials Evaluation, Vol. 43, 1985, pp 541-546.
26. Schiekelmann, R.J., 'Non destructive testing of bonded joints, recent developments in testing system', - Non Destructive Testing, Vol. 8, 1975, pp 100-110.
27. Engl, V., Smiths, G., 'Requirement for data acquisition during ultrasonic testing, search techniques and defect analysis, new procedures in Non destructive testing', Proceedings of the Germany-US workshop, Saarbrucken, Germany, 1982, Springer-Verlag Berlin, 1983.
28. Pople, C.H., Owen, R.C., 'Ultrasonic NDT instrumentation developments in the CEGB ', Non Destructive Testing, Proceedings of the 4th European conference, London, U.K., Vol. 1, Sept. 1987, pp.518-529.
29. McNab, A., Young, H., 'An expert system for NDT Ultrasonics', Non Destructive Testing, Proceedings of the 4th European conference, London, U.K., Vol. 1, Sept. 1987, pp 551-557.
30. Shukla, D., 'Ultrasonic scanning of fibre composites : design, fabrication and analysis', M. Tech thesis report , March 1987.
31. Operating instructions manual of Ultrasonic Flaw Detector model UFD 6255 , ECIL, Hyderabad, India.
32. Users Manual for DT 2801 Series, Data Translation Inc, Locke Drive, Marlboro.
33. Users Manual for PCLAB, Data Translation Inc, Locke Drive, Marlboro.
34. Users manual for PIP image processing card, Matrox Electronic Corporation.
35. Prashant Kumar, Agarwal, B D., Kishore, N.N., 'Experimental studies of ballisticaly impacted composite laminates', progress report of project PK/ME/ARDB/8708.

## APPENDIX - A

### SPECIFICATIONS OF DT-28Ø5 A/D SUBSYSTEM

| | |
|---|---|
| Number of Analog Inputs | 8 Differrential Inputs |
| Resolution | 12 bits |
| Channel Acquisition Time to within 1/2 LSB | 12Ø microseconds |
| **A/D throughput to System Memory** | **6ØØØ samples per second** |
| Software Programmable Gain Range | 1, 1Ø, 1ØØ, 5ØØ |
| Input Ranges | Unipolar or Bipolar |
| Unipolar Input Ranges | Ø to +1ØV, Ø to +1V, Ø to +1ØØmV, Ø to 2Ø mV full scale, depending on programmable gain setting |
| Bipolar Input Ranges | +/-1ØV, +/-1V, +/-1ØØmV, +/-2ØmV full scale, depending on programmable gain setting |
| Output Data Codes | Straigt Binary (unipolar) Offset Binary (bipolar) |
| Input Impedence | 1ØØ megaohms, 1ØØpF |
| Maximum Input Voltage Without Damage, power on | +/-3ØV |
| Maximum Input Voltage Without damage, power off | +/-2ØV |
| Sample and hold droop rate | Ø.1mV/ms |

# APPENDIX - B

## SPECIFICATIONS OF THE IMAGE PROSCESSING CARD

BUS:

-IBM pc plug-in.

Display Memory Acess:

- on board pixel address pointer registers
- DMA transfers

Special Functions:

- Software verticle and horizontal pans
- Software enabled zoom
- Input and output video lookup tables
- Software selectable lookup table maps
- Video bus

Video Timing:

- Active Video: 51.2 µs
- Horizontal Sync Frequency:15.75 KHz
- Horizontal Sync Width: 4.8µs
- Vertical Sync Frequency: 60 Hz (American)50 Hz(European)
- Vertical Sync Width: 190.5µs

Memory Acess:

- Software enabled auto-increment capabilityin 512 - 512 mode to improve transfer speed for both video RAM and LUT RAM access
- Fully transperent memory in both display and grab modes with very fast access

DMA Access:

- Non-interrupt or interrupt driven DMA
- DMA channel is strap selectable and software readable

I/O:

- 16 bit input output address
- Interrupt level 4 (IRQ 4)

## APPENDIX C

### PRECAUTIONS

The present set up was developed by interfacing an ultrasonic flaw detector and stepper motor circuit to the A/D card which involves analog and digital voltage waveforms. The procedure given below should be strictly followed in the given sequence while switching on the circuits for data transfer. Otherwise serious damage may occur to A/D card , UFD or PC-XT.

a) Fill in the immersion tank with water and clamp the specimen.

b) Switch on the PC-XT and run the ADSET software. This sets A/D card to accept the data.

c) Switch on the power supply to stepper motor circuit and peak detector circuit.

e) Bring the transducers to the required position by manual control switch and set the scan size on preset counters.

d) Switch on the UFD and adjust the gain control such that the received signal **peak** is always visible on the UFD screen.

f) Run ADTRIG software which commands A/D card to wait till data comes.

g) Press the switch for automatic scanning and start the data transfer.

h) When the set size is scanned, ADTRIG will automatically stop the A/D card acquiring further data and echo the same on the PC monitor. Now switch off UFD first and then switch off the power supplies for the peak detector and stepper motor control. Your data file is ready for further processing.